



# **NAVAL POSTGRADUATE SCHOOL**

**MONTEREY, CALIFORNIA**

## **THESIS**

**OPERATING AND SUPPORT COSTS AND  
AFFORDABILITY OF A 324 SHIP NAVAL BATTLE  
FORCE**

by

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December 2011

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**OPERATING AND SUPPORT COSTS  
AND AFFORDABILITY OF A 324 SHIP NAVAL BATTLE FORCE**

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## **ABSTRACT**

The purpose of this research was to determine both the added operating and support (O&S) costs and affordability of operating and maintaining a future naval battle force of 324 ships as proposed in the Navy's 30-year shipbuilding plan. Cost estimation including regression, 3-year moving averages, point, expert and analogous modeling was used to capture both historical and future O&S costs from FY1991 to FY2024.

With an emphasis on the three main cost drivers, (manpower, fuel and maintenance) which arguably had the largest influence on ships' O&S costs, data were obtained from the Visibility & Management of Operating & Support Cost (VAMOSC) database and various Selected Acquisition Reports (SARs). Analysis and modeling followed suite in order to forecast expected future costs and affordability for a proposed 12.5 percent growth in naval fleet size by FY2024.

Reviewing all 29 classes of ship within the expected FY2024 battle force, normalized results from the cost estimation models yielded a minimum cost growth of 17 percent in O&S costs. Even if budget growth trend rates were to remain steady, negating the possibility of budget decreases, this thesis argues the Navy would still not be able to afford its proposed future battle force in FY2024.

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## **LIST OF ACRONYMS AND ABBREVIATIONS**

CBO	Congressional Budget Office
CNO	Chief of Naval Operations
CRS	Congressional Research Service
FC	Fuel Cost
FY	Fiscal Year
HED	Hybrid Electric Drive
MC	Maintenance Cost
MPC	Manpower Cost
MPN	Military Personnel Navy
OMN	Operation & Maintenance Navy
O&S	Operating and Support
SAR	Selected Acquisition Report
VAMOSC	Visibility & Management of Operating & Support Cost

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## I. INTRODUCTION

### A. BACKGROUND

*“In the past we spent so much effort in areas of research, development and acquisition, because they were tied to the budgets we were receiving, that people didn’t ask too many questions in the area of operations and support.”*

*Ron Rosenthal<sup>1</sup>*

Prior to 2011, the Navy had been required to submit annually to Congress its 30-year shipbuilding plan. In the plan, it laid out an expected timeline for the construction of new naval ships developed and procured over the next three decades in order to maintain the fleet as older ships transition to retirement. Within its FY2003 shipbuilding plan, the Navy announced to Congress its goal to grow and maintain a naval battle force fleet of 375 ships.<sup>2</sup> In FY2006, that plan changed to the more publicized and familiar 313-ship Navy goal. According to Secretary of the Navy, Ray Mabus, and what is also suggested in the Navy’s FY11/12 Shipbuilding Construction (SCN) budgets, that goal has since increased to approximately 324 ships.<sup>3</sup> These numbers are provided and updated annually by the Navy in order to tailor its perceived future needs of the fleet and thereby successfully support its strategic missions against a continuously evolving world environment. As result, the size of the fleet has changed and is continuously changing, with this latest shipbuilding plan finally showing signs of intent to reverse the downward trend over the last 23 years from 568 to 288 ships shown in Figure 1 to the upward trend of 324 ships depicted in Figure 2 before dropping back down.

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<sup>1</sup> From article on GovernmentExecutive.com titled, “Price Check” written by Katherine McIntire Peters on 01AUG2998.

<sup>2</sup> See Table 1 for the breakdown of the Navy’s battle force.

<sup>3</sup> SECNAV Mabus provided a 324 ship shipbuilding goal during a Secretary of the Navy Guest Lecture (SGL) at the Naval Postgraduate School on 29August2011.

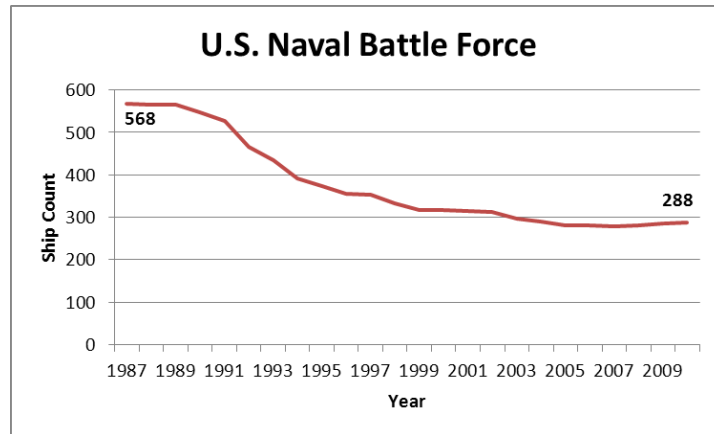


Figure 1. Past-Present U.S. Naval Ship Inventory Levels (From: <sup>4</sup>)

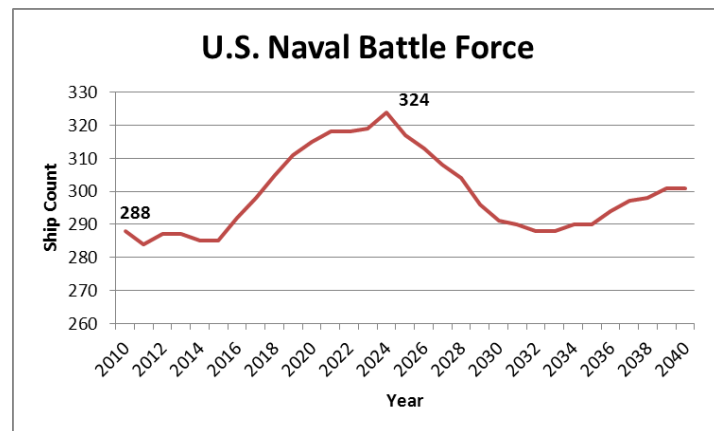


Figure 2. Present-Future U.S. Naval Ship Inventory Levels (From: <sup>5</sup>)

Although the legal requirement for the Navy has since changed to provide only a 10 year shipbuilding plan that is now submitted to Congress by request, the contents of what is provided in the report remain the same. That is to say, the report details the expected number of ships and projected costs to develop and procure them each year out for the next three decades.<sup>6</sup> The Congressional Budget Office (CBO) and Congressional

<sup>4</sup> Numbers derived from the Ronald O'Rourke's CRS report titled, "Navy Force Structure and Shipbuilding Plan: Background and Issues for Congress."

<sup>5</sup> Numbers derived from the Navy's FY2011 Report to Congress on Annual Long-Range Plan for Construction of Naval Vessels.

<sup>6</sup> This includes neither Operating and Support costs nor Disposal costs.

Research Service (CRS) usually provide their own independent analyses of this report to determine the affordability and validity of the Navy's goal as well as their own recommendations to meet it. The affordability aspect is focused on the research and development (R&D) costs as well as the procurement costs associated with these new ships. The validity aspect takes into account the added expectations of ship commissioning and decommissioning timeline alignments to the schedule dictated in the plan to reach the desired number of ships operating in the fleet each year. In the latest CBO and CRS shipbuilding plan analysis reports provided on June 2010 and April 2011 respectively, their collective conclusions were that the Navy has underestimated the costs of adding the suggested 276 ships to the fleet over the next 30 years as well as the validity of reaching and/or maintaining the desired level.<sup>7</sup> What all three of these reports fail to mention are the projected operating and support (O&S) costs/affordability associated with the Navy's goal of adding these ships to the fleet and the budget.

## **B. RESEARCH QUESTION**

When estimating the costs and affordability of a new ship within the shipbuilding plan, the total expected costs to be incurred over the lifecycle of that ship must be considered so as to not further understate the budgetary requirements of these ventures. The four cost areas within a lifecycle cost are categorized as:

- Research and Development (R&D)
- Procurement (otherwise known as Investment)
- Operating and Support (O&S)
- Disposal

As seen in a typical life cycle cost structure for a ship, Figure 3 clearly shows that O&S costs make up the majority of the lifecycle costs overshadowing the other three. In

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<sup>7</sup> Following the near completion of this thesis, an updated CRS report was published dated 13October2011.

fact, those costs usually comprise 70–80 percent of the total lifecycle costs.<sup>8</sup> A breakdown of these O&S categories is located in Table 26 of Appendix A.

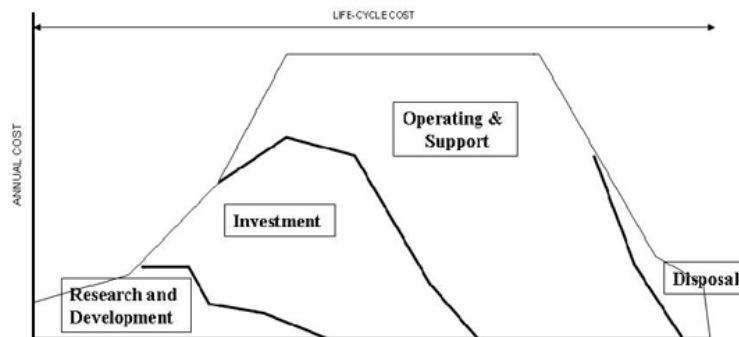


Figure 3. The Four Areas of a Lifecycle (From: <sup>9</sup>)

Since these particular costs make up the bulk of a ship’s lifecycle costs and therefore consume a higher percentage of the Navy’s budget, it is imperative to know what these cost estimates are; that they be included in future shipbuilding plans; and that an affordability analysis be conducted to determine the validity of the shipbuilding goal. This is especially true because as Vice Admiral McCoy acknowledged in the Washington Times, “the current defense budget does not provide what the Navy needs.”<sup>10</sup> As cost drivers such as manpower, fuel and/or maintenance continue to drive O&S costs upward and strain the Navy’s Operation and Maintenance (OMN) and Military Personnel (MPN) budgets each year, knowing what these future costs will be will lead to less of a likelihood of future negligence in both budgetary planning and execution as more ships are added to the mix.

### C. OBJECTIVE

The intent of this thesis is first to determine the specific makeup of the 324 ship battle force fleet in FY2024. Secondly, to estimate the expected future operating and

<sup>8</sup> Marion Eggenberger - Navy’s Acquisition Logistics and Total Ownership Cost Branch Head.

<sup>9</sup> Source: Defense Acquisition Guidebook dated 18March2011.

<sup>10</sup> From Washington Times article titled, “Navy Fleet Needs Funding, Forbes Says” written by Stephen Levy on 13July2011.

support costs to be incurred by the Navy in order to, thirdly, determine the affordability of operating it. Using mostly regression analysis to develop parametric cost estimating models but with some point and analogous estimates as well, a cost estimate was used to forecast the expected O&S costs likely to be incurred by the Navy. Those expected costs were used to determine whether or not the announced 12.5 percent growth in the Navy fleet could realistically be afforded based on current and implied future initiatives.<sup>11</sup>

#### **D. ORGANIZATION OF THE PAPER**

Chapter II of this paper provides a literature review and model testing of previous cost estimating research in the field of O&S costs for the Navy. Chapter III describes the data and three-part methodology used to construct the parametric cost models and analyze the projected costs and affordability in FY2024. Chapters IV and V are comprised of the data analysis of the cost estimating and affordability respectively, followed by Chapter VI's conclusion and pertinent appendixes.

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<sup>11</sup> Based on the increase from a FY2010 inventory of 288 ships to an expected 324 ships in FY2024.

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## **II. LITERATURE REVIEW AND TESTING OF PAST MODELS**

There have been several research studies completed in the past which have focused on operating and support costs of the Navy but none have gone so far as to measure the future O&S costs 10–20 years from the present in order to determine whether or not such costs could be afforded. A few thesis research studies listed below centered their attention on the determination and identification of cost relationships among the various cost factors that seemingly drive operating and support costs for the Navy. Other studies narrowed their attention to more specific factors that may affect these O&S costs.

### **A. LITERATURE REVIEW**

In Ting's 1993 thesis entitled, "Estimating Operating and Support Cost Models for U.S. Naval Ships," he examined Manpower, Material, Maintenance and Overhaul costs derived from the Visibility & Management of Operating & Support Cost (VAMOSOC) system in order to construct simple univariate cost models.<sup>12</sup> In doing so, his research analysis concluded that cost relationships did in fact exist across the spectrum of cost variables, with the manpower factor having the largest impact on costs. Although this manpower conclusion is true when taken over the average as seen in Figure 4 of the next section, the more current data throughout the remainder of this paper will show that maintenance actually overtakes the effects of manpower in driving operational costs in 10 of the 29 classes of ship analyzed.

In Brandt's 1999 thesis entitled, "A parametric Cost Model for Estimating Operating and Support Costs of U.S. Navy (Non-Nuclear) Surface Ships," he too examined cost relationships among different independent variables using a 13 year data set ranging from 1984–1996. From his regression analysis, he was able to construct three univariate cost estimating equations, any one of which could be used to determine the

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<sup>12</sup> Visibility & Management of Operating & Support Cost (VAMOSOC) is a web-enabled management information system that collects and reports historical Navy/USMC/MSO O&S costs on an annual basis. [www.vamosc.navy.mil](http://www.vamosc.navy.mil)

total annual operating and support costs for any given type of ship at any time with the exception of submarines and aircraft carriers. The three variables he used were Ship Light Displacement (weight), Ship Overall Length, and Manpower. His assumption for use of these variables was that annual O&S costs for any ship within a class did not change from year to year, not including effects of inflation. That is to say, as long as these variables did not change, so too the cost would remain unchanged. As shown in the next section, this assumption no longer holds validity since there are numerous variable cost effects that drive overall costs, such as increasing manning, fuel and maintenance costs, which indicate that O&S costs do in fact change from year to year.

In Hascall's et al. 2003 professional report entitled, "Analysis of the Ship Ops Model's Accuracy in Predicting U.S. Naval Ship Operating Cost," the premise of the study was to test the accuracy of the Navy's then-current cost estimating model which did not encompass total operating and support costs but instead just operations and maintenance.<sup>13</sup> This model consisted of the use of several elaborate Microsoft Excel spreadsheets which included input spreadsheets, calculation spreadsheets, summary spreadsheets, and informational spreadsheets; all for use in estimating the 1B1B sub-activity budget within the larger Operation and Maintenance, Navy (OMN) budget. Ship operational costs such as charter, fuel, utilities, temporary additional duty, and operating target (includes repair parts and consumable purchases) can all be found within this sub-activity and three-year averages mixed with various cost factors were used to derive these cost estimates. From the study's findings, a more reliable forecasting model was recommended using a mixture of three-year averages or simple linear regression equations depending on the type of ship and its location in either the Atlantic or Pacific Fleet.

In Gorman's 2003 thesis entitled, "Effect of Optempo on Ship Operational Costs," he examined the effects between operational tempo and operational costs to determine if a relationship actually existed. Analysis of burn rate data and expenditures among several ship classes was performed to access a possible relationship, but

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<sup>13</sup> Operating and Support includes manpower costs whereby Operation and Maintenance does not.

unfortunately his analysis proved inconclusive. “There is no significant relationship between OPTEMPO and expenditure...not to say a relationship cannot be found.” (Gorman, 2003)

## **B. TESTING OF PAST MODELS**

In an attempt to abstain from “reinventing the wheel” by constructing new parametric equations for use within this thesis analysis, a diligent effort was made to use the models already constructed by either Ting or Brandt. As will be discussed, neither set of models was able to be successfully utilized for this thesis. Therefore, new cost relationships and models were required.

### **1. Ting’s Model**

Ting derived four O&S regression cost models, one for each of the Manpower, Material, Maintenance and Overhaul costs factors. The results from these four were added to finally calculate the total O&S cost for one ship. For example, his models for manpower and material were:

$$MP = b_0 + b_1 OFFNAVY + b_2 ENLNAVY + E$$

and

$$MAT = b_0 + b_1 \ln(HRSUWAY) + b_2 \ln(BBLSPRHR) + E$$

where,

MP and MAT are manpower costs and material costs

*OFFNAVY* and *ENLNAVY* are officer and enlisted levels

$\ln(HRSUWAY)$  is natural logarithm of steaming hours underway

$\ln(BBLSPRHR)$  is natural logarithm of barrels of fuel per steaming hour

$B_{0,1,2}$  are coefficients

E is error

When applying updated VAMOSC data from 1991–2010 to these two models for various classes of ships, regression results continuously yielded poor Adjusted R<sup>2</sup>, Significance-F, and/or P-values which were below acceptable levels.<sup>14</sup> For instance, depending on the class of ship, Ting’s MP equation would only yield acceptable regression results if the officer or enlisted variable was either completely removed or at least replaced with the fiscal year (FY) variable. In almost every case, using total manpower instead of distinguishing between officers and enlisted as the first variable while also including fiscal year as the second variable, would yield an acceptable result. One example of an acceptable model found was:

$$MP = b_0 + b_1 \text{TotalManning} + b_2 \text{FY} + E.$$

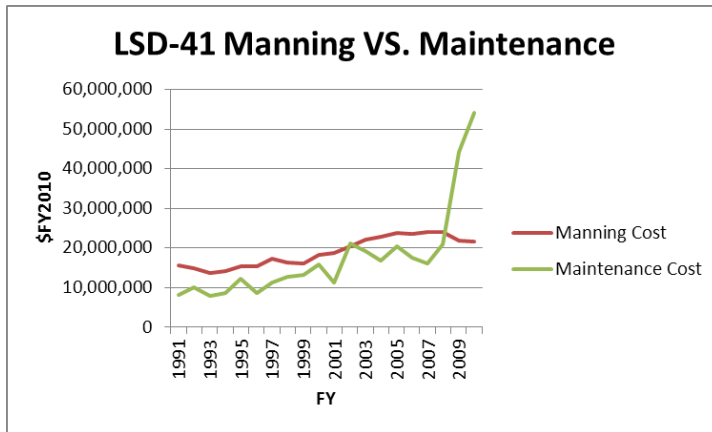
\*No acceptable/successful results were yielded using Ting’s MAT model.

Additional focus was also placed on Ting’s research statement that the manpower factor had the largest impact on costs. Although this statement was true on average using more updated data, preliminary sampling has shown that about 35 percent of the different classes of ship assessed show that manpower was in fact not the largest impact during the entire life time of a ship. As seen in Figure 4 depicting historical data for the average LSD-41 class of ship, by FY2009, maintenance costs overtook the effects of manpower in driving operational costs.<sup>15</sup>

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<sup>14</sup> Acceptable limits are Adjusted R<sup>2</sup> values of .9 or higher and Significance-F and P-values of .1 or lower. Adjusted R<sup>2</sup> values answer the question of whether the regression model should be used over simply taking an average instead. F-significance values answer the question of whether the regression model is a good model or not. And P-values answer the question of whether or not the corresponding independent variables support the model.

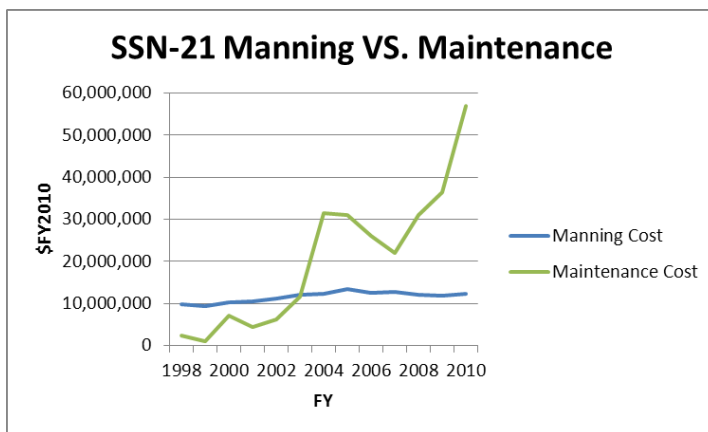
<sup>15</sup> LSD-41 is a type of Dock Landing Ship.



**Manning costs are larger on average**

Figure 4. Manning cost vs. Maintenance cost

A more prevalent example could be seen in Figure 5 in which the data sample from the SSN-21 class submarine clearly showed that although manpower has larger effects in overall costs in the earlier years of the program, it was surpassed by maintenance costs in 2004 making the manning cost on average less of a cost driver than maintenance.<sup>16</sup> As illustrated in Chapter IV, there were several examples of ships in which maintenance costs dominate O&S costs entirely.



**Manning costs are less on average.**

Figure 5. Manning cost vs. Maintenance cost

<sup>16</sup> SSN-21 is type of Fast Attack Nuclear Submarine.

## 2. Brandt's Model

Brandt created three univariate cost estimation equations with which to estimate the total annual operating and support costs associated with any type of U.S. Navy ship. Each of the three equations' single independent variable (X) represented ship light displacement, manpower, or ship length respectively. These equations were:

- $Y = 111,302X^{.618}$
- $Y = 285,215X^{.75}$
- $Y = 1223X^{1.6}$

Using the FY2010 LSD-41 Whidbey Island amphibious class ship data as a sample derived from VAMOSC and JANES, below are the calculations and final estimates in FY2010 constant dollars.

- $Y = 111,302(16,708 \text{ tons})^{.618} = \underline{\$66.4M}$
- $Y = 285,215(298 \text{ personnel})^{.75} = \underline{\$29.9M}$
- $Y = 1223(609 \text{ ft.})^{1.6} = \underline{\$51.3M}$

As seen from the outputs, the range of operating and support costs for a LSD-41 class ship in FY2010 would be \$29.9M to \$66.4M depending on which variable equation was decided on. The actual O&S costs recorded in VAMOSC was \$82.7M which was 176 percent higher than the lowest estimate and 24.5 percent higher than the highest estimate. Based on this inadequate/outdated costing model, it was determined that a new model was required that employed cost estimating relationships but assumed annual costs did in fact change from year to year and other factors such as variable manning, fuel and maintenance costs were a more accurate means for measuring these costs.

### **III. DATA DESCRIPTION AND METHODOLOGY**

#### **A. DATA DESCRIPTION**

This thesis utilized historical O&S cost data supplied by either the Visibility & Management of Operating & Support Costs (VAMOSC) ship database maintained by the Naval Center for Cost Analysis (NCCA) or from the various Selected Acquisition Reports (SAR) maintained by the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics.<sup>17</sup> Since the bulk of this thesis relied on parametric cost estimations using regression analysis, most of the cost data were obtained from the VAMOSC system.

Within the VAMOSC system, specific historical cost data for all classes of ship within the current FY2010 battle force fleet were compiled from either the “Ship” or “Military Sealift Command” universe/databases. The use of either database was dependent on the particular class of ship reviewed. Figure 6 illustrates the arrangement of the historical cost data elements into four main categories listed within the Ships universe. Since this thesis will argue that most costs on a ship are a result of manning, fuel and/or maintenance costs, those were the key areas of focus from which cost data were mostly drawn. Manning costs from section 1.1 and fuel costs under POL within section 1.2 were both taken from the Direct Unit Cost category. Maintenance costs were also drawn from a subsection (repair parts) of section 1.2 as well as from the entire 2.0 and 3.0 categories. Total O&S costs for a class of ship each year were simply the sum of all categories listed.

The Military Sealift Command database was divided into six categories which consisted of unit level manpower, unit operations, maintenance, sustaining support, continuing system improvements and indirect support.

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<sup>17</sup> SARs located on Defense Acquisition Management Information Retrieval (DAMIR) website. <https://ebiz.acq.osd.mil/DAMIR/PortalMain/DamirPortal.aspx>

Of note, this was the same breakdown found in the Selected Acquisition Reports used as point estimates on some of the ships in this thesis. The areas from which cost data were drawn in this database were the first three categories mentioned.

<u>1.0 Direct Unit Cost</u>	<u>3.0 Maintenance &amp; Modernization – Depot</u>
1.1 Personnel	3.1 Maintenance - Scheduled – Depot
1.2 Unit Level Consumption	3.2 Maintenance - Nonscheduled - Depot
1.3 Purchased Services	3.3 Fleet Modernization
	3.4 Aviation Launch & Recovery Equipment
<u>2.0 Maintenance - Intermediate</u>	3.5 Field Change Installation
2.1 Labor - Intermediate Maintenance	3.6 Equipment Rework
2.2 Material - Intermediate Maintenance	3.7 Design Services Allocation
2.3 Commercial Industrial Services	3.8 PERA, SUBMEPP Planning & Procurement
	3.9 Other Depot
	<u>4.0 Other Operating and Support</u>
	4.1 Training
	4.2 Publications
	4.3 Engineering & Technical Services
	4.4 Software Support
	4.5 Ammunition Handling

Figure 6. Major Cost Elements under Ships Universe (From: <sup>18</sup>)

With the assumption that the decade from 1991–2000 would encompass a period of low OPTEMPO and the decade from 2001–2010 would encompass a high OPTEMPO for the Navy, the historical data span used in this research was 20 years ranging from FY1991 to FY2010 in an attempt to capture both.<sup>19</sup> All data remained in FY2010 constant dollars and all subsequent analysis, equations, and estimates were also in FY2010 constant dollars.<sup>20</sup>

Although it was assumed that the VAMOSC database provided accurate, up-to-date, and therefore reliable data, it is worth mentioning some discrepancies discovered in the reporting. As further discussed in Chapter IV, there were a few classes of ships which seemed to under-report or perhaps be missing certain cost data. For instance, the

<sup>18</sup> Recreated from the VAMOSC Overview Brief.

<sup>19</sup> 2010 is the most recent year for which complete data were available.

<sup>20</sup> Constant dollars adjust for inflation, providing a constant purchasing power metric.

surveillance ships (AGOS) had negligible manpower costs listed within their database. That is to say, reported costs were so little that it was as if no crew were being paid. In another example, Figure 63 of APPENDIX A showed just one of a couple of classes of ships which had costs reports in both the Ship and Military Sealift Command databases but the costs reported in the two databases were very much different from each other. This includes significant differences in manning numbers as mentioned earlier. Despite these discrepancies, the VAMOSC database as a whole was still considered a strong valid and reliable source for use as a historical cost retrieval system for the battle force.

## B. METHODOLOGY

Before determining whether or not the Navy could afford a 324 ship battle force in FY2024, the future costs expected to be incurred from this particular size fleet were required to be known. Before the costs of the fleet could be calculated, the particular inventory or number of ships in each class that make up the force must have been known, both currently and in the future. The methodology used towards gaining all these answers and analysis is displayed in Figure 7.

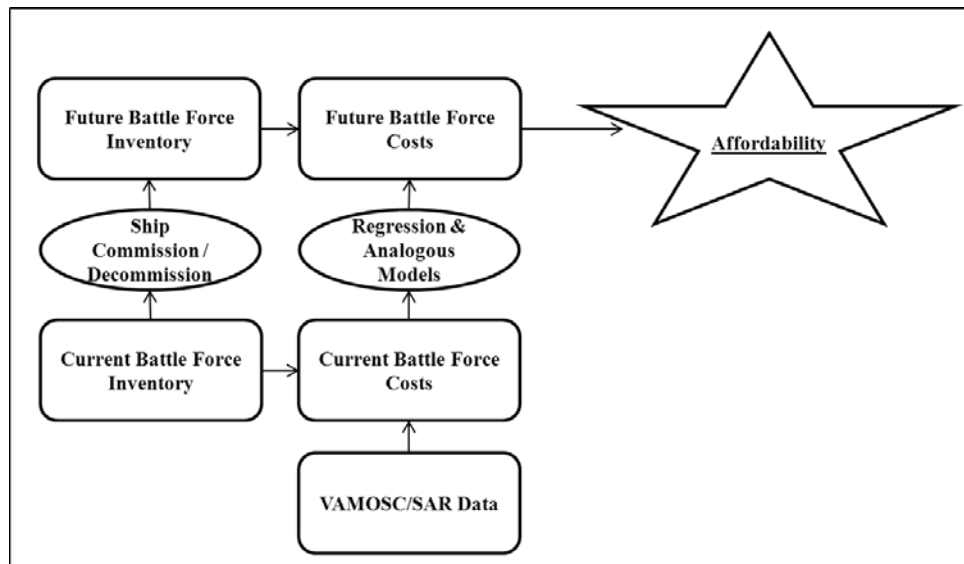


Figure 7. Methodology Flowchart

## 1. Assumptions & Limitations

- VAMOSC data were up-to-date and reliable.
- Costs did not include embarked squadrons onboard ships.
- Manpower costs for submarines, Littoral Combat Ships (LCS) and Joint High Speed Vessels (JHSV) were less than true costs since they only captured half of the Blue-Gold crew size.<sup>21</sup>
- Full annual O&S costs were assigned to ship inventory counts in FY2010 and FY2024 regardless if a particular ship was commissioned or decommissioned sometime during that year.
- Costs associated with all Guided Missile Frigates (FFG-7) in the active naval reserve were the same as those not in the reserves.
- New ships commissioned to replace older ones as they decommission between FY2010–2024 retained the same cost estimates as their predecessors within their same class.
- Uses of the specific cost estimation models in this thesis for each class of ship were the best options to use since they provided the most accurate solutions when tested with actual recorded costs in the past.
- The cost estimates for the entire battle force in both FY2010 and FY2024 were underestimates of actual costs due to most of the cost models yielding low estimates on average as well as due to the limitations listed above.
- New factors such as energy and additional reduced manning initiatives were not considered when creating cost estimation models since they did not affect historical costs.

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<sup>21</sup> The Blue-Gold crew size concept is based on a rotational basis in which one crew, either Gold or Blue, is at sea while the other is ashore.

## **2. Ship Inventory**

The total inventory of battle force ships and numbers of each type/class of ship will vary from year to year as a result of the complex relationship among procurement, design and construction times, commissioning/decommissioning, funding availability, industrial base capacity and war-fighting priorities.

## **3. Cost Estimation Models**

When creating the cost models for the different classes of ships in the battle force, 13 different independent variables were tested in various combinations in the search for successful cost estimating relationships (CER) that would yield statistically strong estimation models. These variables were fuel cost, fuel gallons, burn rate, price-per gallon, fiscal year, manning cost, manning number, enlisted number, officer number, underway steaming hours, labor hours, age, and maintenance cost. Of these, fuel gallons, burn rate, labor hours and age were eventually discarded from the equations since they offered no viable solutions or relationships within the regression models.

The primary goal was to utilize parametric regression models that not only passed the proper statistical checkpoints but also produced strong cost estimates when tested and compared to actual costs incurred within each class of ship over the period of time reviewed. Whenever regression models were either not feasible or not applicable, the use of point, analogous or three-year moving average cost estimations took their place. Cases in which a lack of feasibility or applicability were present was when for instance, a class of ship either had too few data points to be able to develop statistically a significant regression equation or its data were too volatile to yield one, and cases in which no cost data were reported since that class of ship may not have entered the fleet yet.

### ***a. Regression Models***

With the goal of creating cost estimates that represented the top three cost drivers which were manpower costs, fuel costs and maintenance costs, a work breakdown structure approach was used in creating each series of regression equations (Equations 2–4) which were then simplified into one written regression equation (Equation 1) listed for

each class of ship throughout Chapter IV. As illustrated in Figure 8, by using the top three cost drivers as the independent variables and the overall cost as the dependent variable, successful regression equations were achieved to yield O&S cost estimates for most classes of ships.

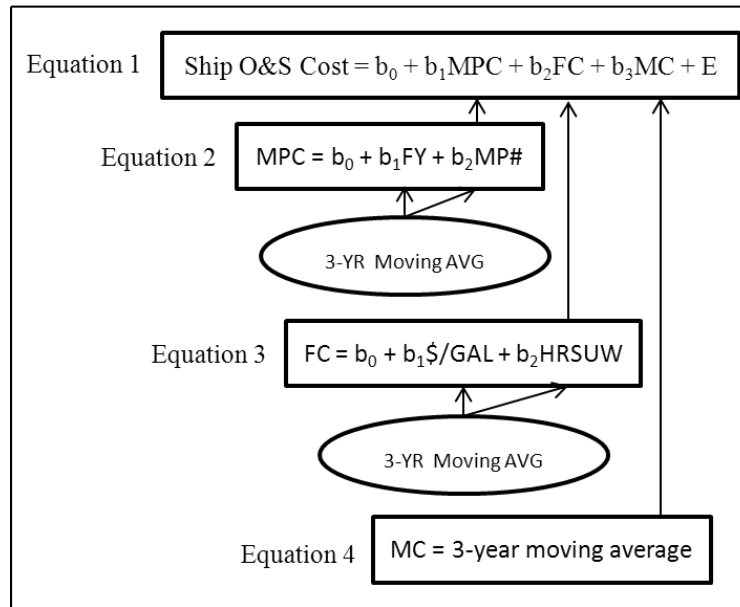


Figure 8. Work Breakdown Structure of Regression Models

Equation 1 was the main regression equation calculated in each class which would serve as the flagship for obtaining total O&S costs per ship.<sup>22</sup> MPC (manpower cost), FC (fuel cost) and MC (maintenance cost) served as the independent variables in this equation. In order to input the dollar values in each of these three independent variables, additional regression equations were then calculated within each of these cost areas as well. In certain classes of ships, MPC or FC may have been excluded within the flagship model.

Equation 2 is as an example of the manpower regression equation in which fiscal year and crew size (manning number) were used to find the manning costs for each class of ship. Of note, in some cases, the breakdown of manning number into officer and

<sup>22</sup> Actual costs and future estimated costs are all in constant FY2010 dollars.

enlisted variables was required instead. A three-year moving average was used to obtain the values for these independent variables which then aggregated into Equation 2 to find MPC. The calculated answer from this regression equation would then be aggregated upward, serving as the input for MPC in Equation 1. In certain classes of ships, MPC may have been excluded from Equation 1 which would then mitigate the need for an Equation 2. In other cases, no satisfactory regression equation was achievable for Equation 2 so a three-year moving average was used instead and would remain as “MPC” in the written/simplified equation of the analysis section.

The same process was used for Equation 3 in which fuel costs were calculated. Price per gallon of fuel and steaming hours underway served as the two independent variables with total fuel cost as the dependent variable. A three-year moving average was used to obtain the values for the independent variables and a final FC solution would then be aggregated back up to Equation 1. In certain cases, such as with the nuclear powered carriers and submarines, this cost area was excluded altogether since fuel costs were not a factor. If no FC regression was possible for other classes of ship, a three-year moving average was used in its place and would appear as “FC” in the simplified equation within the analysis section.

For Equation 4, in all cases, no satisfactory regression models were able to be achieved for maintenance costs. That is to say, regression equations were produced but due to poor statistical values such as adjusted coefficient of determination (R-squared) values well below .9, they were discarded and three-year moving averages were used instead; the solutions to which were then aggregated up into Equation 1 and remained as “MC” within the equation.<sup>23</sup>

#### ***b. Regression Tables***

APPENDIX B contains the correlation coefficient matrixes tables associated with all the satisfactory regression models used for the FY2024 battle force

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<sup>23</sup> R-squared ( $R^2$ ) is a regression statistic which tells how reliable the measured data will fall directly on the best fit line. The larger the value, the better fit and for this thesis, .9 or higher was the benchmark in accepting the use of a regression model.

cost estimates. These correlation tests were completed on all independent variables used within each class of ship to determine how each variable affected the others. Values of .7 or higher or -.7 or lower were used in this thesis as the benchmark for signs of high correlation or in another words, strong linear relation of some kind.<sup>24</sup> Since these tables were compiled data from Equations 1 through 4 of each ship class, it is worth reminding that although there may be several noticeable values above .7 and below -.7 in the tables, it did not mean they correlate with each other since they may not have been a part of the same equation or may have served as either a dependent or independent variable at the time. For example, manning cost and fiscal year may have shown a .8 correlation but since manning cost was a dependent variable and fiscal year an independent variable within Equation 2, this value was acceptable. If manning number on the other hand had the .8 value with fiscal year, this would have been an example of high correlation since they both were independent variables within Equation 2.

APPENDIX C contains the compiled regression results tables from each of the classes of ships in which regression models were used for the FY2024 cost estimates. These tables contain the F-Significance, Adjusted R-squared values and coefficient values for each equation. Again, since estimates for maintenance costs did not rely on regression, its rows were left empty.

*c. Point Estimates and Analogous Estimates*

For ships that were so new that there was only one year's worth of historical cost data, a point estimate was used as the cost estimating model. In another words, the total recorded O&S cost for a particular ship during the one year it was measured was brought forward and used as the FY2024 cost as well. This technique was also applied to the ships that have not yet been built and so relied on the single estimated

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<sup>24</sup> Correlation coefficient is a statistical test that outputs a number between -1 and 1 which indicates how strong of a relation two variables may have with each other. A perfect relationship is with a correlation coefficient of -1 or 1 and a correlation coefficient of zero indicates no existence of a relationship between the two variables. For this thesis, a benchmark of .7 or -.7 was used.

O&S cost listed in their Selected Acquisition Reports (SAR).<sup>25</sup> For future ships that had no SAR data, an analogous estimate was used based on similar platforms of which cost data were available, either historically via VAMOSC or through expert testimony.

#### **4. Affordability**

Affordability analysis was done while looking at several factors. The first was the level of accuracy in the cost estimation models used in this thesis to calculate the final cost estimates for FY2024. In other words, how under, over or close to exact were the costs. The second was addressing the sensitivity that a particular mix of ships in the battle force each year would potentially have on costs. The third was measuring historical and future OMN and MPN budget trends compared to historical and future ship count trends to determine feasibility of financing these ships. Finally, a look at how a few cost reduction initiatives in place by the Navy would financially impact (save) money and thereby help efforts towards affordability.

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<sup>25</sup> Located in the Defense Acquisition Management Information Retrieval (DAMIR) portal site.  
<https://ebiz.acq.osd.mil/DAMIR/PortalMain/DamirPortal.aspx>

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## IV. DATA ANALYSIS – BATTLE FORCE INVENTORIES AND COST ESTIMATION MODELS

### A. BATTLE FORCE INVENTORIES

The compilation of ship types counted toward the Navy’s battle force is defined by the Secretary of the Navy’s battle force instruction, 5030.8A.<sup>26</sup> Specifically, “Battle force ships are commissioned United States ship (USS) warships capable of contributing to combat operations, or a United States naval ship (USNS) that contributes directly to Navy war fighting or support missions.” (SECNAVINST 5030.8A) As indicated in Table 1, the Navy currently considers 26 out of 79 different types of vessels to be a part of the battle force inventory. The remaining vessels, shown in Table 2 were not counted towards the battle force inventory since they do not meet the criteria defined within the instruction.

<b>Counted Towards Battle Force</b>			
<b>Warships</b>	<b>Designator</b>	<b>Combat Logistics Ship</b>	<b>Designator</b>
Multi-purpose Aircraft Carrier Nuclear-Powered	CVN	Ammunition Ship	AE
Guided Missile Cruiser	CG	Dry Cargo and Ammunition Ship	AKE
Guided Missile Destroyer	DDG	Oiler	AO
Guided Missile Frigate	FFG	Fast Combat Support Ship	AOE
Littoral Combat Ship	LCS	Combat Store Ship	AFS
Attack Submarine Nuclear-Powered	SSN	<b>Fleet Support Ships</b>	<b>Designator</b>
Ballistic Missile Submarine Nuclear-Powered	SSBN	Command Ship	LCC
Guided Missile Submarine Nuclear-Powered	SSGN	Submarine Tender	AS
Amphibious Assault Ship General Purpose	LHA	Joint High Speed Vessel	JHSV
Amphibious Assault Ship Multi-Purpose	LHD	Surveillance	AGOS
Amphibious Transport Dock	LPD	Salvage Ship	ARS
Dock Landing Ship	LSD	Fleet Ocean Tug	ATF
Mine Countermeasures Ship	MCM	Mobile Landing Platform	MLP
		Dry Cargo/Ammunition	T-AKE

Table 1. Ships Counted in US Naval Battle Force as of FY11 (From: <sup>27</sup>)

<sup>26</sup> Dated 08February2011

<sup>27</sup> Compiled from SECNAVINST 5030.8A

<b><u>Not Counted Towards Battle Force</u></b>		
<b><u>Auxiliary Ships</u></b>	<b><u>Designator</u></b>	<b><u>Combatant Craft</u></b>
Auxiliary Crane Ship	ACS	11 Various Types
Missile Range Instrumentation Ship	AGM	<b><u>Support Craft</u></b>
Oceanographic Research Ship	AGOR	32 Various Types
Surveying Ship	AGS	
Hospital Ship	AH	
Cargo Ship	AKE	
Vehicle Cargo Ship	AKR	
Transport Oiler	AOT	
Cable Repairing Ship	ARC	
Aviation Logistics Support Ship	AVB	

Table 2. Ships Not Counted in US Naval Battle Force as of FY11 (From: <sup>28</sup>)

During the period between 2010 and 2024, the types of ships, classes of ships and individual ships themselves will all change as new vessels are procured and commissioned into the fleet while others are decommissioned and removed.<sup>29</sup> As mentioned in the previous chapter, before one can address the affordability and O&S costs of the Navy's battle force mix, the actual composition of that force must be known first and foremost.

Dissecting and transcribing the ships by type located in Table 1 into the more specific list of ships by class shown in Table 3, the appropriate inclusions of ship inventory quantities were identified. From FY2010 to FY2024, the Navy's battle force was expected to increase by 12.5 percent (36 ships) from 288 to 324 ships. This was based on cross-related data largely drawn from the Navy's FY2011 30 year shipbuilding plan, the FY2012 Shipbuilding and Conversion Navy Budget Estimates report and the Naval Vessel Registry maintained by Naval Sea Systems Command (NAVSEA).

<sup>28</sup> Compiled from SECNAVINST 5030.8A

<sup>29</sup> For classification purposes, the hierarchy for classifying ships is INDIVIDUAL Ship→CLASS of Ship→TYPE of Ship→CATEGORY of Ship.

<b>Ship Class</b>	<b>Designator</b>	<b>FY2010 Ship Count</b>	<b>FY2024 Ship Count</b>
Multi-purpose Aircraft Carrier Nuclear-Powered	CVN-65	1	0
Multi-purpose Aircraft Carrier Nuclear-Powered	CVN-68	10	9
Multi-purpose Aircraft Carrier Nuclear-Powered	CVN-78	0	2
Guided Missile Cruiser	CG-47	22	11
Guided Missile Destroyer	DDG-51	59	80
Guided Missile Destroyer	DDG-1000	0	3
Guided Missile Frigate	FFG-7	29	0
Littoral Combat Ship	LCS-1	2	28
Attack Submarine Nuclear-Powered	SSN-21	3	3
Attack Submarine Nuclear-Powered	SSN-688	42	22
Attack Submarine Nuclear-Powered	SSN-774	8	21
Ballistic Missile Submarine Nuclear-Powered	SSBN-726	14	14
Guided Missile Submarine Nuclear-Powered	SSGN-726	4	4
Amphibious Assault Ship General Purpose	LHA-1	2	0
Amphibious Assault Ship General Purpose	LHA-6	0	3
Amphibious Assault Ship Multi-Purpose	LHD-1	8	8
Amphibious Transport Dock	LPD-4	4	0
Amphibious Transport Dock	LPD-17	5	11
Dock Landing Ship	LSD-41	8	8
Dock Landing Ship	LSD-49	4	4
Dock Landing Ship	LSD-X	0	2
Mine Countermeasures Ship	MCM-1	14	14
Ammunition Ship	AE-26	3	0
Dry Cargo and Ammunition Ship	AKE-1	10	11
Oiler	AO-187	15	15
Fast Combat Support Ship	AOE-6	4	4
Command Ship	LCC-19	2	2
Submarine Tender	AS-39	2	2
Joint High Speed Vessel	JHSV-1	0	21
Surveillance	AGOS-19	4	4
Surveillance	AGOS-23	1	2
Salvage Ship	ARS-50	4	4
Fleet Ocean Tug	ATF-166	4	6
Mobile Landing Platform	MLP-1	0	3
Dry Cargo/Ammunition	T-AKE	0	3
<b>Total Battle Force Inventory</b>		<b>288</b>	<b>324</b>

Table 3. Battle Force Inventory Levels in FY2010 & FY2024 (From: <sup>30</sup>)

<sup>30</sup> Ship counts compiled from OPNAV N8F's "Report to Congress on Annual Long-Range Plan for Construction of Naval Vessels for FY2011," FY2012 Shipbuilding and Conversion Navy Budget Estimates dated February 2011, "Highlights of the Department of the Navy FY2012" report and the Naval Vessel Registry.

Highlighting the classes of ships within the table was done to indicate what seem to be the largest changes within the battle force ship mix during this period. That is to say, the changes that warrant the most attention in this table are the:

Current or future additions of:

- CVN-78
- DDG-1000
- LCS-1 (Significant increase)
- LHA-6
- LSD-X
- JHSV-1
- MLP-1
- T-AKE (Added to Fleet Support Category)

Current or future subtractions of:

- CVN-65
- FFG-7
- LHA-1
- LPD-4
- AE-26

Of these, the significant changes are the Enterprise class nuclear carrier's (CVN-68) replacement by the Gerald R. Ford class nuclear carrier, the Oliver Hazard Perry class frigate's (FFG-7) replacement by the Littoral Combat Ship (LCS) and a significant increase in the fleet support section of the battle force as the Joint High Speed Vessel (JHSV) enters the fleet.

## **B. COST ESTIMATION MODELS**

In the following 29 subsections are the cost modeling and analysis for each of 29 classes of ship expected to be in the Navy's FY2024 battle force.<sup>31</sup> Actual recorded O&S costs were individually distinguished within the first figure provided under each class section, depicting each of its main costs drivers. The regression equation, cost estimates and regression comparison tests then follow after that, in both figure and table format. Table 4 is a compiled summary from these sections listing the cost estimation

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<sup>31</sup> Table 3 lists 30 for FY2024 but "T-AKE" is same type of platform as "AKE-1."

models used to create the future cost estimates for each class of ship. Table 5 is a compiled summary from these sections listing the future O&S cost estimates for each class of ship, derived from the cost models mentioned.

<u>O&amp;S Cost</u>			<u>Model Used</u>		
<b>CVN-68</b>	Class	Regression	<b>LSD-49</b>	Class	Regression
	Manpower	Regression		Manpower	3-YR Moving AVG
	Maintenance	3-YR Moving AVG		Fuel	Regression
<b>CVN-78</b>	Class	Point Estimate		Maintenance	3-YR Moving AVG
<b>CG-47</b>	Class	Regression	<b>LSD-X</b>	Class	Annalogous (LSD-49)
	Manpower	Regression	<b>MCM-1</b>	Class	Regression
	Fuel	Regression		Manpower	Regression
	Maintenance	3-YR Moving AVG		Maintenance	3-YR Moving AVG
<b>DDG-51</b>	Class	Regression	<b>AKE-1</b>	Class	3-YR Moving AVG
	Manpower	Regression	<b>AO-187</b>	Class	Regression
	Fuel	Regression		Manpower	3-YR Moving AVG
	Maintenance	3-YR Moving AVG		Fuel	3-YR Moving AVG
<b>DDG-1000</b>	Class	Point Estimate		Maintenance	3-YR Moving AVG
<b>LCS-1</b>	Class	Point Estimate	<b>AOE-6</b>	Class	Regression
<b>SSN-21</b>	Class	Regression		Manpower	3-YR Moving AVG
	Manpower	Regression		Fuel	Regression
	Maintenance	3-YR Moving AVG		Maintenance	3-YR Moving AVG
<b>SSN-688</b>	Class	Regression	<b>LCC-19</b>	Class	Regression
	Manpower	Regression		Manpower	Regression
	Maintenance	3-YR Moving AVG		Fuel	3-YR Moving AVG
<b>SSN-774</b>	Class	Regression		Maintenance	3-YR Moving AVG
	Maintenance	3-YR Moving AVG	<b>AS-39</b>	Class	Regression
<b>SSBN-726</b>	Class	3-YR Moving AVG		Manpower	3-YR Moving AVG
<b>SSGN-726</b>	Class	Regression		Fuel	3-YR Moving AVG
	Manpower	Regression		Maintenance	3-YR Moving AVG
	Maintenance	3-YR Moving AVG	<b>JHSV-1</b>	Class	Point Estimate
<b>LHA-6</b>	Class	Point Estimate	<b>AGOS-19</b>	Class	Regression
<b>LHD-1</b>	Class	Regression		Manpower	3-YR Moving AVG
	Manpower	Regression		Energy (Fuel)	3-YR Moving AVG
	Fuel	3-YR Moving AVG	<b>AGOS-23</b>	Class	Regression
	Maintenance	3-YR Moving AVG		Manpower	3-YR Moving AVG
<b>LPD-17</b>	Class	3-YR Moving AVG		Energy (Fuel)	3-YR Moving AVG
<b>LSD-41</b>	Class	Regression	<b>ARS-50</b>	Class	3-YR Moving AVG
	Manpower	Regression	<b>ATF-166</b>	Class	3-YR Moving AVG
	Maintenance	3-YR Moving AVG	<b>MLP-1</b>	Class	Expert/Annalogous

Table 4. Summary of Cost Estimation Models Used

O&S Cost Per Ship (Constant FY2010 Millions of Dollars)														
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
CVN-68	408.0	408.8	418.6	422.2	428.3	433.0	439.7	443.8	449.2	454.4	459.7	465.0	470.3	475.6
CVN-78	0.0	0.0	0.0	0.0	392.5	392.5	392.5	392.5	392.5	392.5	392.5	392.5	392.5	392.5
CG-47	65.9	66.4	66.2	67.3	67.7	68.2	68.8	69.3	69.9	70.4	70.0	71.5	72.1	72.6
DDG-51	46.2	46.8	47.6	48.0	48.6	49.2	49.8	50.4	50.9	51.5	52.1	52.6	53.2	53.8
DDG-1000	0.0	0.0	83.3	83.3	83.3	83.3	83.3	83.8	83.8	83.8	83.8	83.8	83.8	83.8
LCS-1	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4
SSN-21	55.3	58.8	61.7	58.8	60.0	60.4	60.0	60.3	60.4	60.4	60.6	60.7	60.8	60.9
SSN-688	37.8	37.0	37.3	38.1	38.2	38.5	39.0	39.3	39.6	40.0	40.3	40.7	41.0	41.4
SSN-774	20.8	22.0	23.1	22.0	22.3	22.5	22.3	22.4	22.4	22.3	22.3	22.3	22.3	22.3
SSBN-726	77.1	73.2	76.8	76.2	76.6	76.7	76.7	76.7	76.7	76.7	76.7	76.7	76.7	76.7
SSGN-726	48.3	48.0	48.1	48.5	48.5	48.7	48.9	49.1	49.2	49.4	49.6	49.8	49.9	50.1
LHA-6	0.0	0.0	123.3	123.3	123.3	123.3	123.3	123.3	123.3	123.3	123.3	123.3	123.3	123.3
LHD-1	165.8	167.4	170.5	172.7	175.0	177.5	179.8	182.2	184.6	187.0	189.3	191.7	194.1	196.5
LPD-17	46.9	47.5	48.8	47.7	48.0	48.2	48.0	48.1	48.1	48.0	48.1	48.1	48.1	48.1
LSD-41	72.3	78.3	79.5	78.1	80.0	80.6	81.0	81.9	82.6	83.2	84.0	84.6	85.3	86.0
LSD-49	50.0	50.7	52.4	5.0	51.3	51.6	51.3	51.4	51.4	51.4	51.4	51.4	51.4	51.4
LSD-X	50.0	50.7	52.4	51.0	51.3	51.6	51.3	51.4	51.4	51.4	51.4	51.4	51.4	51.4
MCM-1	14.1	14.5	15.1	15.1	15.4	15.7	15.9	16.4	16.4	16.6	16.9	17.1	17.4	17.6
AKE-1	31.5	31.8	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7	31.7
AO-187	24.7	24.3	24.6	24.5	24.4	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5	24.5
AOE-6	38.4	37.2	36.5	37.3	37.0	36.9	37.1	37.0	37.0	37.0	37.0	37.0	37.0	37.0
LCC-19	94.4	94.9	94.1	97.2	97.8	99.0	100.5	101.7	103.0	104.3	105.5	106.8	108.1	109.4
AS-39	107.8	109.2	112.2	109.7	110.4	110.8	110.3	110.5	110.5	110.4	110.5	110.5	110.5	110.5
JHSV-1	0.0	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7	27.7
AGOS-19	8.4	8.1	8.5	8.3	8.3	8.4	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
AGOS-23	9.7	9.2	9.6	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
ARS-50	10.4	40.5	11.0	10.7	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8
ATF-166	6.4	6.5	6.6	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
MLP-1	0.0	0.0	0.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0

Table 5. Summary of Future O&S Cost Estimates Per Ship<sup>32</sup>

### 1. Nimitz Class Aircraft Carrier (CVN-68)

With recorded O&S costs ranging from \$207.9M in FY1993 on the low end to \$425.3M in FY2004 on the high end, the fluctuations and therefore volatility in costs for this class of ship seemed to make the task of estimating future costs extremely unpredictable. A possible explanation of this variation, as shown in Figure 9, was that unlike manning costs, maintenance costs highly fluctuated each year, driven by for example, ship age, OPTEMPO and perhaps refueling.

<sup>32</sup> The following ships were not included in Table 26 nor were cost estimates calculated since all were scheduled for decommissioning in the next few years (CVN-68, FFG-7, LHA-1, LPD-4 and AE-26).

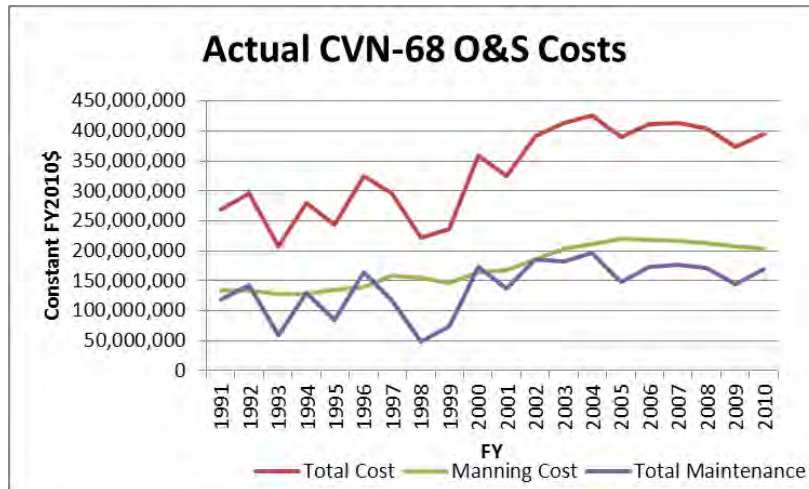


Figure 9. CVN-68 Costs by Top Two Cost Drivers

Despite these challenges, regression analysis was completed and cost estimates made incorporating the calculated coefficients listed in Table 46 of APPENDIX C along with the simplified multivariable regression equation for CVN-68. With no satisfactory regression possible for the maintenance cost factor, a simple moving three-year average was used for this variable. In other words, “ $b_3 + b_4FY + b_5MP$ ” was the MPC (manpower) regression equation within the larger CVN-68 regression equation and “MC” was a simple average in this case.

$$\begin{aligned} \text{Total CVN-68 O\&S Cost} &= b_0 + b_1MPC + b_2MC + E \\ &= b_0 + b_1(b_3 + b_4FY + b_5MP\#) + b_2MC + E \end{aligned}$$

Where,

$B_{0-5}$  = Coefficients, E= Error

MPC and MC = Manpower and Maintenance Costs respectively

FY and MP# = Fiscal Year and Manpower #

A comparison of the results of the regression equation with the actual O&S costs recorded over the last 20 years was completed and as shown in Figure 10, the future cost

estimates line (Est Total Cost) followed the actual costs line fairly well. Table 6 also shows this but in numeric form pointing out that with an average cost variance of -.3 percent, the model seemed to be very strong. Using this model for future predictions yielded an O&S cost in FY2024 of \$475.6M per ship which was a 20.5 percent growth from its FY2010 actual recorded cost of \$394.4M.

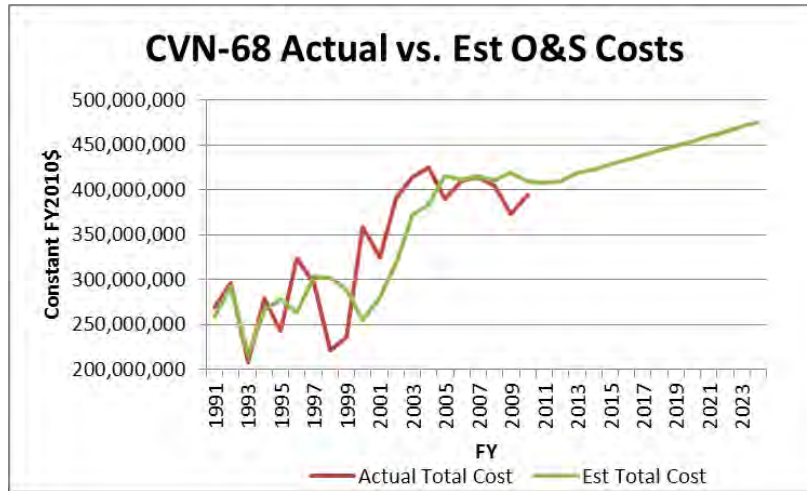


Figure 10. Testing and Projection of CVN-68 Regression Model

<b>FY</b>	<b>Actual Total Cost</b>	<b>Est Total Cost</b>	<b>Variance</b>	<b>Variance %</b>
1991	269,558,959	259,077,067	-10,481,892	-3.9%
1992	296,419,290	292,099,618	-4,319,672	-1.5%
1993	207,929,805	216,513,591	8,583,786	4.1%
1994	279,776,510	266,480,181	-13,296,329	-4.8%
1995	243,640,806	277,451,161	33,810,355	13.9%
1996	324,292,514	263,579,317	-60,713,197	-18.7%
1997	295,600,563	303,610,920	8,010,357	2.7%
1998	222,011,637	301,601,220	79,589,583	35.8%
1999	235,762,361	289,233,644	53,471,283	22.7%
2000	359,208,029	255,203,766	-104,004,263	-29.0%
2001	325,416,340	279,887,048	-45,529,292	-14.0%
2002	391,116,755	319,319,175	-71,797,580	-18.4%
2003	413,681,628	372,058,107	-41,623,521	-10.1%
2004	425,342,551	384,411,523	-40,931,028	-9.6%
2005	390,176,230	414,929,130	24,752,900	6.3%
2006	410,761,837	411,336,420	574,583	0.1%
2007	413,770,191	414,748,599	978,408	0.2%
2008	404,934,526	410,413,454	5,478,928	1.4%
2009	373,279,881	418,321,722	45,041,841	12.1%
2010	394,402,327	408,960,032	14,557,705	3.7%
AVERAGE			-5,892,352	-0.3%

Table 6. CVN-68 O&S Cost Variances

## 2. Gerald R. Ford Class Aircraft Carrier (CVN-78)

The first of the new nuclear powered Gerald R. Ford class aircraft carriers is not scheduled to enter the fleet until FY2015. As such, no historical O&S cost data were available for regression modeling. Therefore, a simple point estimate sufficed as a means of constructing the future O&S costs for this platform.<sup>33</sup> See Figure 11.

<sup>33</sup> O&S cost estimate provided by the Selected Acquisition Report (SAR) within the Defense Acquisition Management Information Retrieval (DAMIR) site.  
<https://ebiz.acq.osd.mil/DAMIR/PortalMain/DamirPortal.aspx>

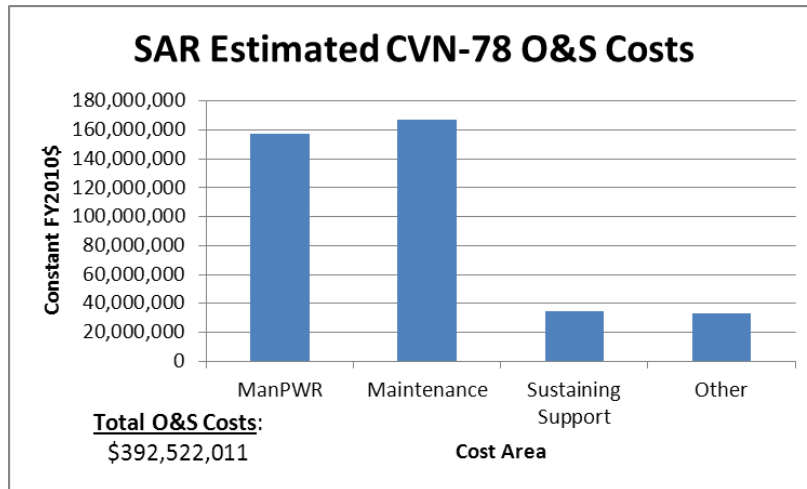


Figure 11. CVN-78 Costs by Area Based on SAR Report

Manpower costs are expected to be less than those on the CVN-68 carriers due to reduced manning initiatives but maintenance is estimated to be higher, ultimately causing O&S costs to be similar for both platforms.<sup>34</sup> As shown in Figure 11, total future O&S costs are expected to be \$392.5M per ship. Since this is a point estimate, this same cost was used for the cost estimated in FY2024 with a total of two of these ships accounted in the battle force by then. Of note, use of this point estimate neglects any potential growth or declines in O&S costs throughout the projected forward.

### 3. Ticonderoga Class Cruiser (CG-47)

The top three cost drivers for the Ticonderoga class cruiser O&S costs have all maintained a fairly steady profile throughout the span of the 20 years in review. Manpower costs grew at an almost linear rate while fuel costs appeared to have flat-lined across the board. It was not until the mid and late 2000's did maintenance costs begin to influence overall costs more dramatically as seen by the matching contours in both the "Total Cost" and "Total Maintenance" lines within Figure 12.

<sup>34</sup> Similar costs are observed when compared in FY2010. However, since CVN-68 will continue to grow based on its cost model whereas no growth will occur for CVN-78 due to its costs being a static point estimate, by FY2024 the costs between the two were no longer similar.

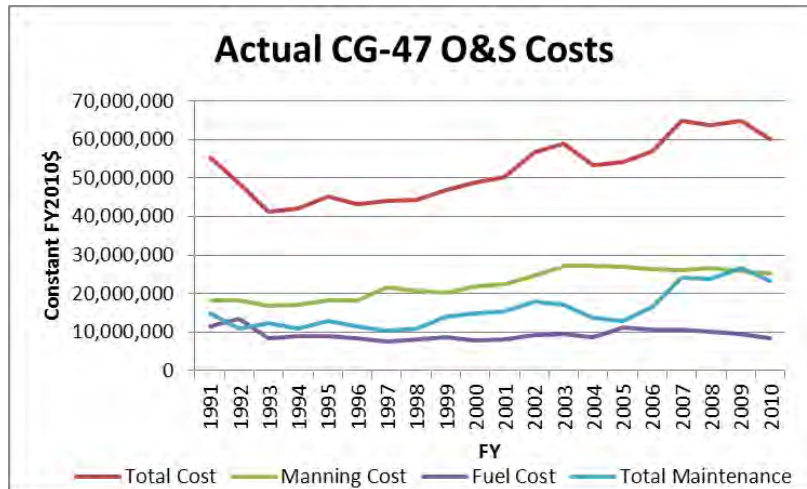


Figure 12. CG-47 Cost by Top Three Cost Drivers

$$\begin{aligned} \text{Total CG-47 O\&S Cost} &= b_0 + b_1\text{MPC} + b_2\text{FC} + b_3\text{MC} + E \\ &= b_0 + b_1(b_4 + b_5\text{FY} + b_6\text{MP\#}) + b_2(b_7 + b_8\$GAL + b_9\text{HRSUW}) + b_3\text{MC} + E \end{aligned}$$

Where,

$B_{0-9}$  = Coefficients, E= Error

MPC, FC, MC = Manpower, Fuel, and Maintenance Costs respectively

FY, MP#, \$GAL, HRSUW = Fiscal Year, Manpower #, Price/Gallon Fuel, and Steaming Hours Underway

A comparison of the results of the regression equation with the actual O&S costs recorded over the last 20 years was completed and as shown in Figure 13, the future costs estimates line (Est Total Cost) followed fairly well to the actual costs line. Table 7 also shows this but in numeric form pointing out that with an average cost variance of negative one percent, the model seemed to slightly underestimate the costs but nonetheless remained strong. Using this model for future predictions yielded an O&S cost in FY2024 of \$72.6M per ship which was a 21 percent growth from its FY2010 actual recorded cost of \$60M.

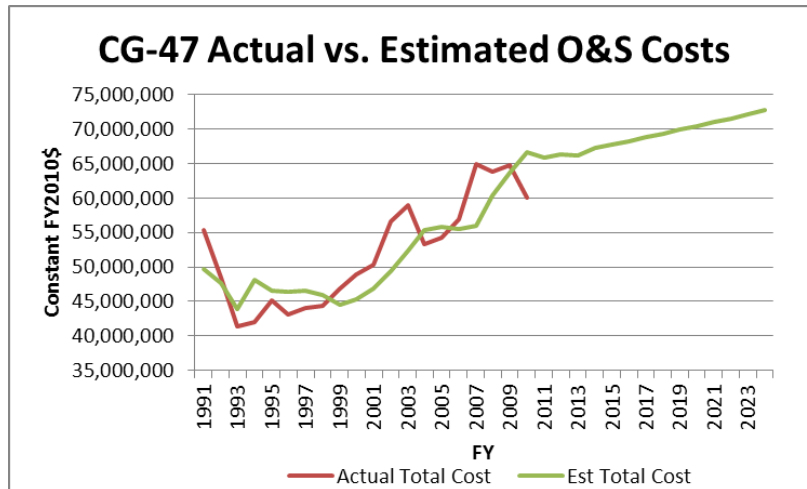


Figure 13. Testing and Projection of CG-47 Regression Model

FY	Actual Total Cost	Est Total Cost	Variance	Variance %
1991	55,365,623	49,635,801	-5,729,822	-10.3%
1992	48,479,643	47,695,494	-784,149	-1.6%
1993	41,342,733	43,905,355	2,562,622	6.2%
1994	41,985,899	48,184,936	6,199,037	14.8%
1995	45,131,190	46,545,533	1,414,343	3.1%
1996	43,191,183	46,390,404	3,199,221	7.4%
1997	43,991,071	46,536,691	2,545,620	5.8%
1998	44,400,895	45,880,283	1,479,388	3.3%
1999	46,915,456	44,595,641	-2,319,815	-4.9%
2000	48,967,445	45,237,710	-3,729,735	-7.6%
2001	50,372,955	46,906,826	-3,466,129	-6.9%
2002	56,639,168	49,335,356	-7,303,812	-12.9%
2003	58,976,976	52,329,932	-6,647,044	-11.3%
2004	53,311,723	55,343,934	2,032,211	3.8%
2005	54,266,977	55,775,524	1,508,547	2.8%
2006	56,954,479	55,564,852	-1,389,627	-2.4%
2007	64,927,991	55,959,855	-8,968,136	-13.8%
2008	63,833,029	60,321,184	-3,511,845	-5.5%
2009	64,753,171	63,588,951	-1,164,220	-1.8%
2010	59,974,057	66,580,583	6,606,526	11.0%
AVERAGE			-873,341	-1.0%

Table 7. CG-47 O&S Cost Variances

#### 4. Arleigh Burke Class Destroyer (DDG-51)

Unlike the cruiser, the Arleigh Burke destroyer had a significantly different cost profile in regards to its top three cost drivers. Figure 14 depicts both fuel and

maintenance costs appearing to remain steady over the years within a small range of variance that is, while manpower costs have almost doubled and therefore were much larger than the other two.

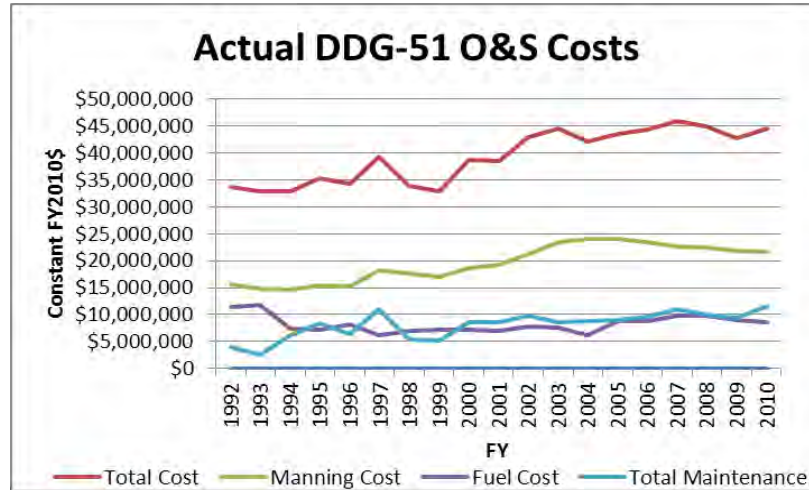


Figure 14. DDG-51 Cost by Top Three Cost Drivers

Referring to Table 31 in APPENDIX B, there was a high correlation (over .7) between the manning and maintenance cost variables when creating the DDG-51 regression equation. High or often called, strong correlation simply implies that there is an above normal relationship between these two independent variables.<sup>35</sup> Since correlation does not imply causation meaning that this high number does not necessarily mean it is causing any interaction between each other, and the cause of this interaction is unknown if any even exists, it was decided to simply ignore this correlation point and still use all variables.

$$\begin{aligned} \text{Total DDG-51 O\&S Cost} &= b_0 + b_1\text{MPC} + b_2\text{FC} + b_3\text{MC} + E \\ &= b_0 + b_1(b_4 + b_5\text{FY} + b_6\text{MP\#}) + b_2(b_7 + b_8\text{\$GAL} + b_9\text{HRSUW}) + b_3\text{MC} + E \end{aligned}$$

<sup>35</sup> Normally accepted levels are below .7 and above -.7 for this thesis.

Where,

$B_{0-9}$  = Coefficients, E= Error

MPC, FC, MC = Manpower, Fuel, and Maintenance Costs respectively

FY, MP#, \$GAL, HRSUW = Fiscal Year, Manpower #, Price/Gallon Fuel, and Steaming Hours Underway

A comparison of the results of the regression equation with the actual O&S costs recorded over the last 19 years was completed and as shown in Figure 15, the future costs estimates line (Est Total Cost) followed fairly well to the actual costs line. Table 8 also shows this but in numeric form pointing out that with an average cost variance of -.5 percent, the model seemed to be very strong. Using this model for future predictions yielded an O&S cost in FY2024 of \$53.8M per ship which was a 21 percent growth from its FY2010 actual recorded cost of \$44.4M.

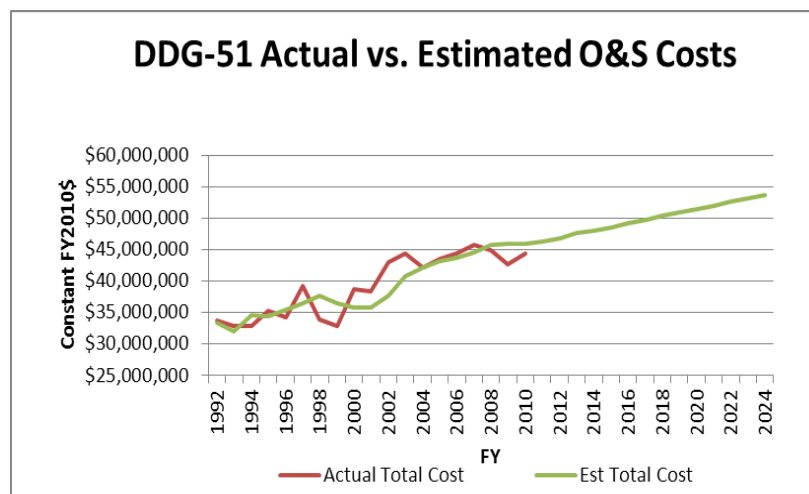


Figure 15. Testing & Projection of DDG-51 Regression Model

<b>FY</b>	<b>Actual Total Cost</b>	<b>Est Total Cost</b>	<b>Variance</b>	<b>Variance %</b>
1992	33,729,743	33,340,298	-389,445	-1.2%
1993	32,928,223	32,078,368	-849,855	-2.6%
1994	32,928,209	34,633,226	1,705,017	5.2%
1995	35,296,175	34,492,811	-803,364	-2.3%
1996	34,202,486	35,526,058	1,323,572	3.9%
1997	39,233,691	36,458,716	-2,774,975	-7.1%
1998	33,889,322	37,634,116	3,744,794	11.1%
1999	32,968,924	36,540,984	3,572,060	10.8%
2000	38,670,381	35,829,136	-2,841,245	-7.3%
2001	38,433,372	35,796,740	-2,636,632	-6.9%
2002	42,963,210	37,710,224	-5,252,986	-12.2%
2003	44,471,210	40,771,083	-3,700,127	-8.3%
2004	42,165,370	42,118,391	-46,979	-0.1%
2005	43,523,831	43,231,960	-291,871	-0.7%
2006	44,402,211	43,810,578	-591,633	-1.3%
2007	45,834,243	44,598,813	-1,235,430	-2.7%
2008	44,861,667	45,722,805	861,138	1.9%
2009	42,741,912	46,037,771	3,295,859	7.7%
2010	44,442,224	45,945,093	1,502,869	3.4%
AVERAGE			-284,697	-0.5%

Table 8. DDG-51 O&S Cost Variances

## 5. Zumwalt Class Destroyer (DDG-1000)

The first of only three DDG-1000 destroyers scheduled for production is not slated to be delivered to the Navy until late FY2013 or early FY2014.<sup>36</sup> Again, similar to the new aircraft carrier, no historical data were available for cost regression modeling so a point estimate was used in its place. The breakdown of O&S costs are shown in Figure 16 with total O&S costs estimated to be \$83M per ship. This was the amount used in FY2024. Again, this point estimate cost remained stagnant and therefore showed no effects of potential growth or decline leading into FY2024.

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<sup>36</sup> Per the Shipbuilding and Conversion Navy (SCN) budget report for FY11.

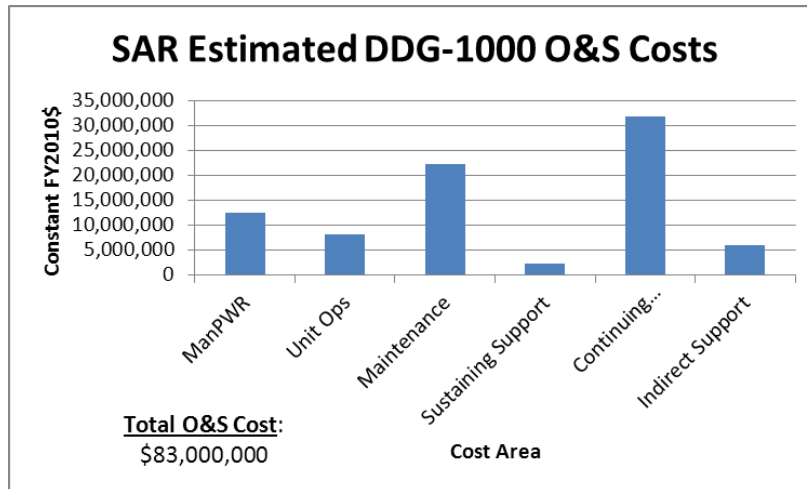


Figure 16. DDG-1000 Costs by Area Based on SAR Report

## 6. Littoral Combat Ship (LCS)

As a new platform, the Littoral Combat Ship has just recently entered the fleet with its first two ships online in FY2010. With only one year of cost data available for analysis, no regression model was possible. Instead, a point estimate of \$36.4M per ship broken down into its three main cost areas show in Figure 17 based on its SAR report was utilized for its FY2024 cost.

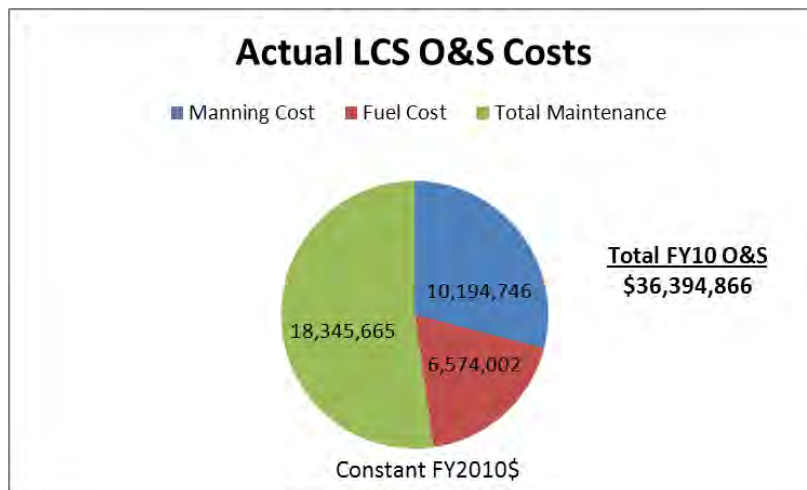


Figure 17. LCS Costs by Top Three Cost Drivers

## 7. Seawolf Class Attack Submarine (SSN-21)

The Seawolf class submarine is a small class of submarines with only three commissioned into the fleet before production was halted. One of, if not the only driver for this decision by the Navy was due to the very quick increases in maintenance costs to operate and maintain such vessels. Tracing the “Total Maintenance” line in Figure 18 from FY2003 onward, maintenance costs have increased by nearly 500 percent over this eight year period while manning costs have remained almost unchanged.

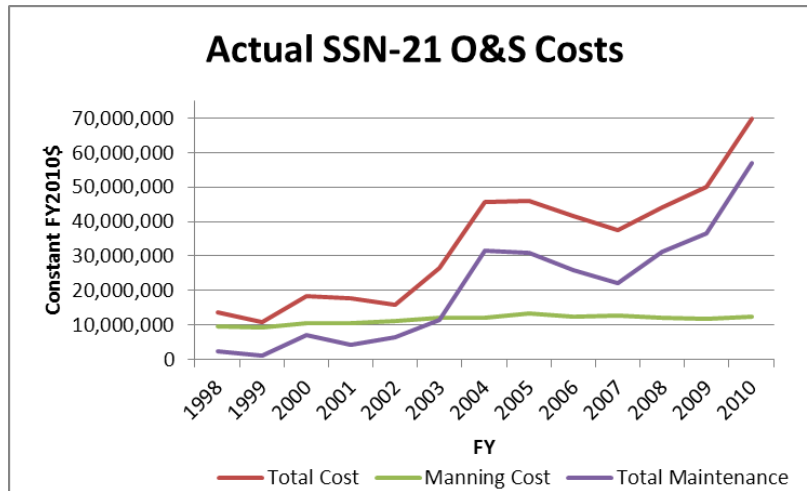


Figure 18. Costs by Top Two Cost Drivers

$$\begin{aligned} \text{Total SSN-21 O\&S Cost} &= b_0 + b_1\text{MPC} + b_2\text{MC} + E \\ &= b_0 + b_1(b_3 + b_4\text{OFF\#} + b_5\text{EL\#} + b_6\text{FY}) + b_2\text{MC} + E \end{aligned}$$

Where,

$B_{0-6}$  = Coefficients,  $E$  = Error

MPC and MC = Manpower and Maintenance Costs respectively

OFF#, EL# and FY = Officer#, Enlisted# and Fiscal Year

Referring to Table 32 in APPENDIX B, there was a high correlation (over .7) between the manning and maintenance cost variables when creating the SSN-21 regression equation. Similarly to what was done with the DDG-51 regression model, it was decided to simply ignore this correlation point and still use all variables.

A comparison of the results of the regression equation with the actual O&S costs recorded over the last 13 years was completed and as shown in Figure 19, the future costs estimates line (Est Total Cost) was a hit and miss in regards to alignment with the actual costs (Actual Total Cost) line but was the best option for future cost estimation in this thesis. Table 9 also shows this but in numeric form pointing out that with an average cost variance of -14.6 percent, the model tends to underestimate the actual O&S costs. Using this model for future predictions yielded an O&S cost in FY2024 of \$60.9M per boat which was a 13 percent decline from its FY2010 actual recorded cost of \$70M. This decrease was based on the assumption that maintenance costs will begin to taper off and settle in the future.

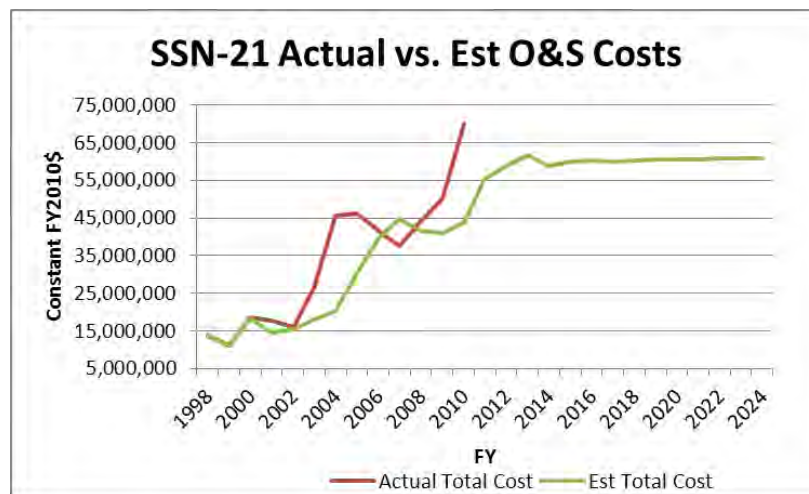


Figure 19. Testing and Projection of SSN-21 Regression Model

FY	Actual Total Cost	Est Total Cost	Variance	Variance %
1998	13,781,369	13,337,889	-443,480	-3.2%
1999	10,955,868	11,311,660	355,792	3.2%
2000	18,471,253	18,415,990	-55,263	-0.3%
2001	17,603,198	14,569,804	-3,033,394	-17.2%
2002	15,960,230	15,493,763	-466,467	-2.9%
2003	26,459,957	18,103,274	-8,356,683	-31.6%
2004	45,614,404	20,411,208	-25,203,196	-55.3%
2005	46,059,168	30,251,247	-15,807,921	-34.3%
2006	41,564,917	39,424,993	-2,139,924	-5.1%
2007	37,513,210	44,641,022	7,127,812	19.0%
2008	44,210,667	41,545,408	-2,665,259	-6.0%
2009	50,165,462	40,853,922	-9,311,540	-18.6%
2010	70,010,637	43,874,823	-26,135,814	-37.3%
AVERAGE			-6,625,795	-14.6%

Table 9. SSN-21 O&S Cost Variances

## 8. Los Angeles Class Attack Submarine (SSN-688)

Similar to the Seawolf class submarines, manning costs remained steady throughout the history of the platform but maintenance costs were volatile. Fortunately for this cost profile, maintenance costs seemed to oscillate in a drawn out and somewhat predictable pattern shown in Figure 20 which the regression model shows through its results in Figure 21.

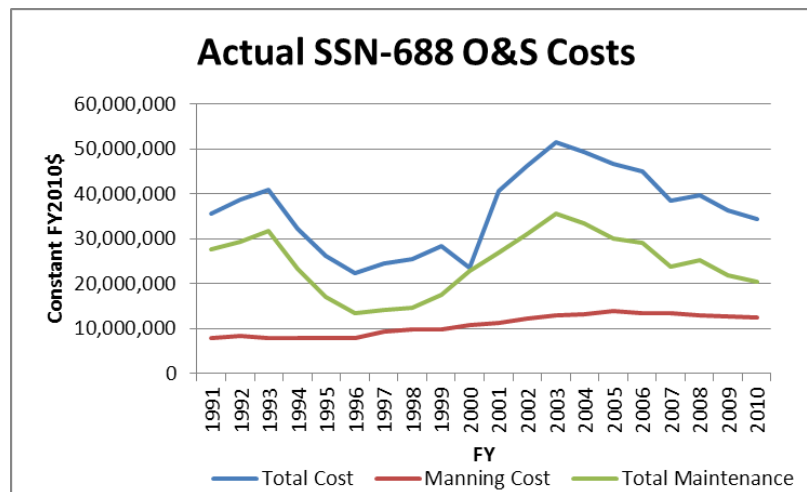


Figure 20. SSN-688 Costs by Top Two Cost Drivers

$$\begin{aligned}\text{Total SSN-688 O\&S Cost} &= b_0 + b_1\text{MPC} + b_2\text{MC} + E \\ &= b_0 + b_1(b_3 + b_4\text{FY} + b_5\text{MP\#}) + b_2\text{MC} + E\end{aligned}$$

Where,

$B_{0-5}$  = Coefficients, E= Error

MPC and MC = Manpower and Maintenance Costs respectively

FY and MP# = Fiscal Year and Manpower #

A comparison of the results of the regression equation with the actual O&S costs recorded over the last 20 years was completed and as shown in Figure 21 and Table 10, the estimation model struggled with matching actual costs to estimated costs, ultimately tending on average, to overestimate costs by 5.3 percent. The use of this model for future predictions yielded an O&S cost in FY2024 of \$41.4M per boat which was a 28 percent growth from its FY2010 actual recorded cost of \$34.5.

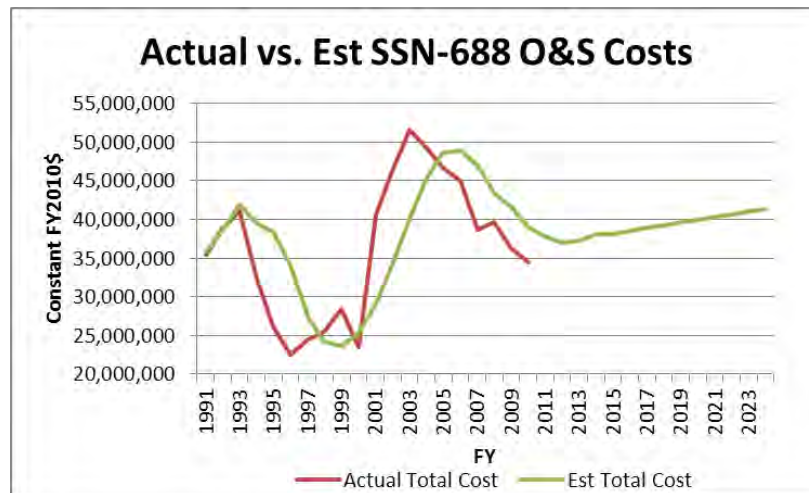


Figure 21. Testing and Projection of SSN-688 O&S Costs

<b>FY</b>	<b>Actual Total Cost</b>	<b>Est Total Cost</b>	<b>Variance</b>	<b>Variance %</b>
1991	35,490,979	35,845,739	354,760	1.0%
1992	38,742,983	38,573,690	-169,293	-0.4%
1993	41,012,050	41,853,080	841,030	2.1%
1994	32,291,407	39,463,533	7,172,126	22.2%
1995	26,193,428	38,346,504	12,153,076	46.4%
1996	22,439,205	34,011,816	11,572,611	51.6%
1997	24,531,467	27,360,056	2,828,589	11.5%
1998	25,456,633	24,139,889	-1,316,744	-5.2%
1999	28,461,215	23,644,560	-4,816,655	-16.9%
2000	23,468,993	25,297,511	1,828,518	7.8%
2001	40,655,676	29,115,940	-11,539,736	-28.4%
2002	46,238,926	34,117,317	-12,121,609	-26.2%
2003	51,573,031	40,025,921	-11,547,110	-22.4%
2004	49,257,402	45,345,943	-3,911,459	-7.9%
2005	46,620,668	48,639,356	2,018,688	4.3%
2006	45,011,307	48,912,890	3,901,583	8.7%
2007	38,603,676	46,971,706	8,368,030	21.7%
2008	39,703,962	43,419,173	3,715,211	9.4%
2009	36,217,564	41,602,526	5,384,962	14.9%
2010	34,491,175	38,869,722	4,378,547	12.7%
AVERAGE			954,756	5.3%

Table 10. SSN-688 O&S Cost Variances

## 9. Virginia Class Attack Submarine (SSN-774)

The Virginia class submarine has been in the fleet just over a half decade producing only five years of cost data. As such, little change was observed in costs with the exception of FY2010 in which maintenance costs nearly tripled. See Figure 22.

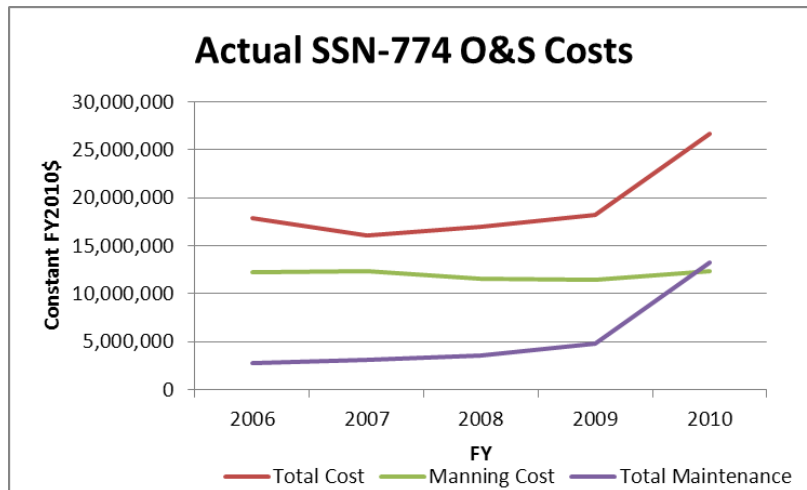


Figure 22. SSN-774 Costs by Top Two Cost Drivers

$$\begin{aligned}\text{Total SSN-774 O\&S Cost} &= b_0 + b_1\text{MC} + E \\ &= b_0 + b_1\text{MC} + E\end{aligned}$$

Where,

$B_{0-1}$  = Coefficients, E= Error

MC = Maintenance Costs respectively

Due to the lack of data points to use to construct a strong regression model, there was little difference between using either a regression model or a three-year moving average as Figures 23 and 24 will demonstrate respectively. Within the regression model, the manning cost variable was excluded due to its prevention of a satisfactory regression result. Therefore, only maintenance was included as the independent variable in this particular case.

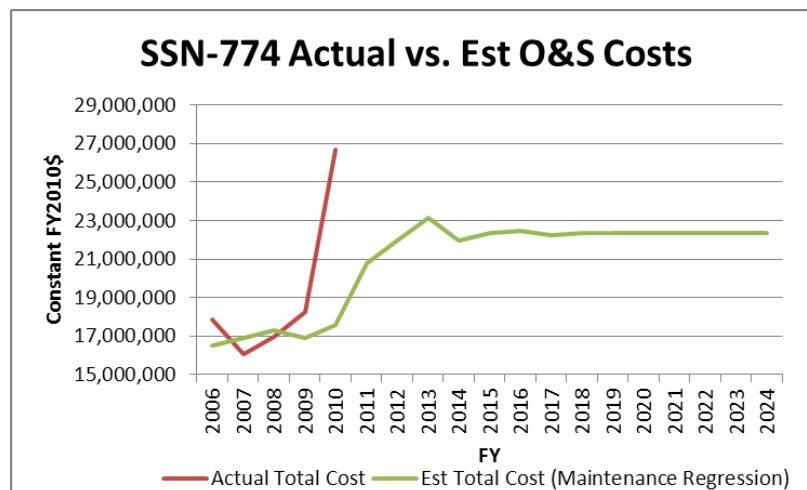


Figure 23. Testing and Projection of SSN-774 O&S Cost (Regression)

A comparison of the results of the regression equation with the actual O&S costs recorded over the last five years was completed. Future predictions yielded an O&S cost in FY2024 of \$22.3M per boat which was a 16 percent decline from its FY2010 actual recorded cost of \$26.7M. This drop was largely based on the simple fact that there were so few data points to analyze which has caused on average, an 8.3 underestimation of the

costs. See Table 11. It was also believed the reduction in costs are contributed the potential tapering off of high maintenance costs as seen in FY2010, eventually returning to a steady pattern.

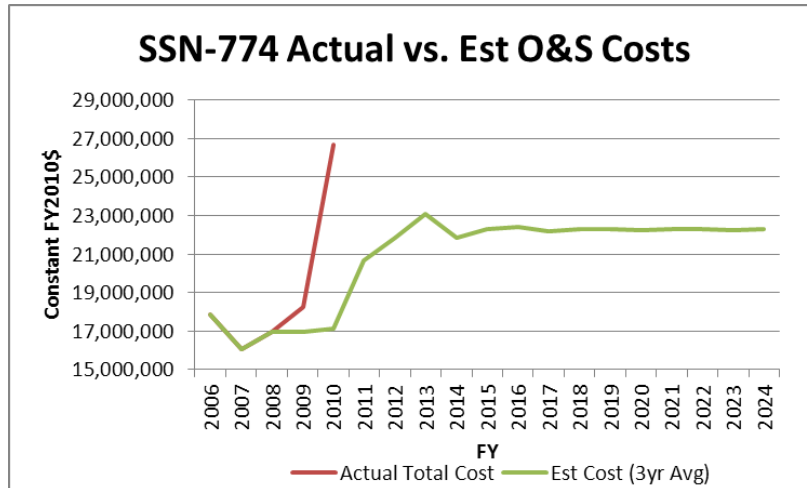


Figure 24. Testing and Projection of SSN-774 O&S Costs (Average)

FY	Actual Total Cost	Est Total Cost	Variance	Variance %
2006	17,839,898	16,531,079	-1,308,819	-7.3%
2007	16,076,004	16,925,157	849,153	5.3%
2008	16,940,299	17,307,278	366,979	2.2%
2009	18,275,150	16,921,171	-1,353,979	-7.4%
2010	26,701,778	17,566,146	-9,135,632	-34.2%
AVERAGE			-2,116,460	-8.3%

Table 11. SSN-774 O&S Cost Variances

## 10. Ohio Class Ballistic Missile Submarine (SSBN-726)

Maintenance costs, illustrated in Figure 25, to maintain and operate the Ohio class submarine over the last 20 years have fluctuated enough that no satisfactory regression model was achievable. Instead, a three-year moving average was used to estimate the future O&S costs expected to be incurred. Comparing the results of the averaging model against the actual O&S costs recorded over the last 20 years, yielded an O&S cost in FY2024 of \$76.7M per boat which was a negligible decrease from its FY2010 actual recorded cost of \$77.2. Refer to Figure 26 and Table 12.

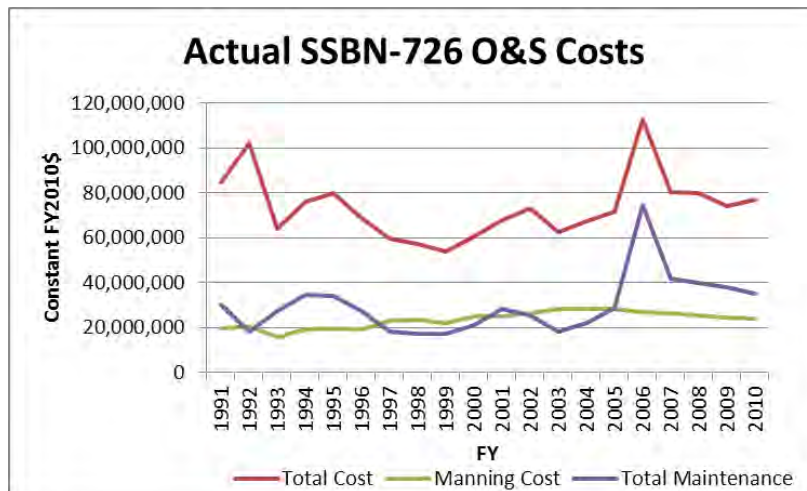


Figure 25. SSBN-726 Costs by Top Two Cost Drivers

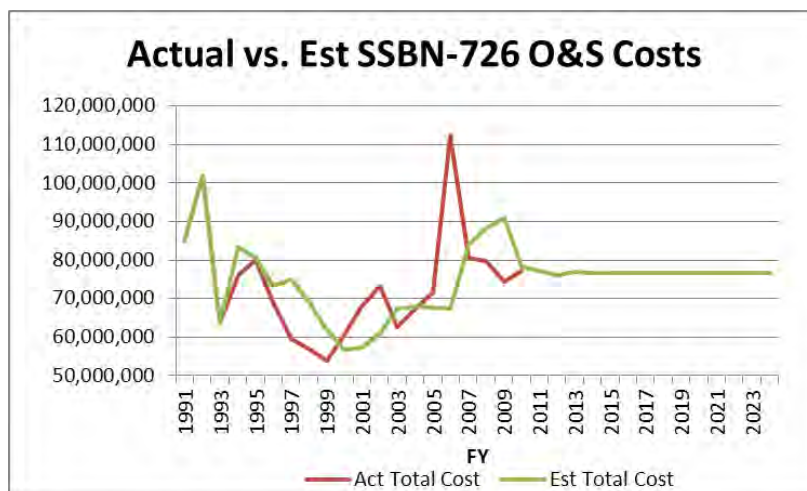


Figure 26. Testing and Projection of SSBN-726 Model

<b>FY</b>	<b>Actual Total Cost</b>	<b>Est Total Cost</b>	<b>Variance</b>	<b>Variance %</b>
1991	84,729,770	84,729,770	0	0.0%
1992	101,956,955	101,956,955	0	0.0%
1993	63,838,355	63,838,355	0	0.0%
1994	75,950,714	83,508,360	7,557,646	10.0%
1995	79,943,038	80,582,008	638,970	0.8%
1996	68,979,280	73,244,036	4,264,756	6.2%
1997	59,431,876	74,957,677	15,525,801	26.1%
1998	56,996,876	69,451,398	12,454,522	21.9%
1999	53,881,698	61,802,677	7,920,979	14.7%
2000	60,539,406	56,770,150	-3,769,256	-6.2%
2001	67,962,847	57,139,327	-10,823,520	-15.9%
2002	73,175,985	60,794,650	-12,381,335	-16.9%
2003	62,621,137	67,226,079	4,604,942	7.4%
2004	67,466,221	67,919,990	453,769	0.7%
2005	71,654,511	67,754,448	-3,900,063	-5.4%
2006	112,445,899	67,247,290	-45,198,609	-40.2%
2007	80,471,141	83,855,544	3,384,403	4.2%
2008	79,858,691	88,190,517	8,331,826	10.4%
2009	74,318,868	90,925,244	16,606,376	22.3%
2010	77,186,338	78,216,233	1,029,895	1.3%
AVERAGE			-3,169,222	-0.4%

Table 12. SSBN-726 O&S Cost Variances

## 11. Ohio Class Guided Missile Submarine (SSGN-726)

The Ohio class submarine suffered two abnormally high years in O&S costs during FY2005 and FY2006. The cause, as shown in Figure 27 was the more than tripling of the maintenance costs for those two years when compared to the years prior to and following these events.

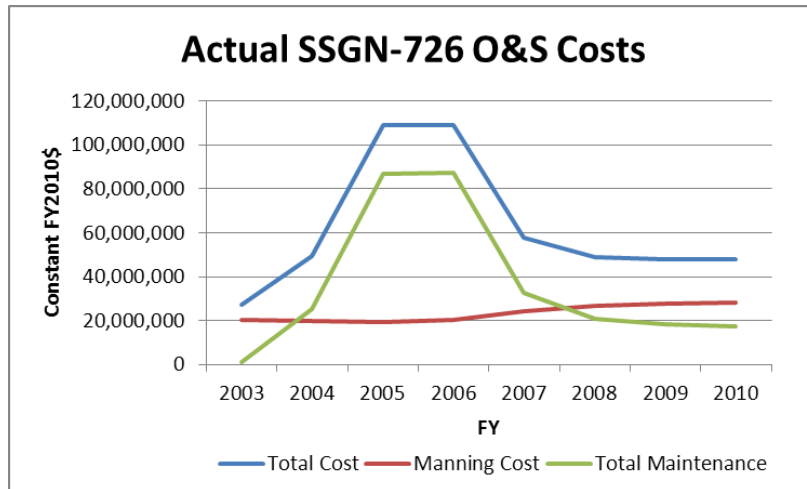


Figure 27. SSGN-726 Costs by Top Two Cost Drivers

Referring to Table 35 in APPENDIX B, there was a high correlation (over .7) between the fiscal year (FY) manning number (MP#) independent variables within the manpower cost regression model. Similarly to what was done with previous regression models that suffered from correlation, and where additional tests/models were created without these variables, it was decided to simply ignore this correlation point and still use all variables since the difference in results seemed negligible.

$$\begin{aligned} \text{Total SSGN-726 O\&S Cost} &= b_0 + b_1\text{MPC} + b_2\text{MC} + E \\ &= b_0 + b_1(b_3 + b_4\text{FY} + b_5\text{MP\#}) + b_2\text{MC} + E \end{aligned}$$

Where,

$B_{0-5}$  = Coefficients, E= Error

MPC and MC = Manpower and Maintenance Costs respectively

FY and MP# = Fiscal Year and Manpower #

A comparison of the results of the regression model with the actual O&S costs recorded over the last 20 years was completed and is as shown in Figure 28, it was difficult predicting the O&S costs due to the two large spikes in maintenance costs

mentioned earlier. This caused a very high over estimation in costs on the average of 32.5 percent as shown in Table 13. Nonetheless, was assumed that these spikes have leveled off just as the rest of Figure 27 shows. Future predictions yielded an O&S cost in FY2024 of \$50.1M per boat which is a 4.6 percent growth from its FY2010 actual recorded cost of \$47.9.

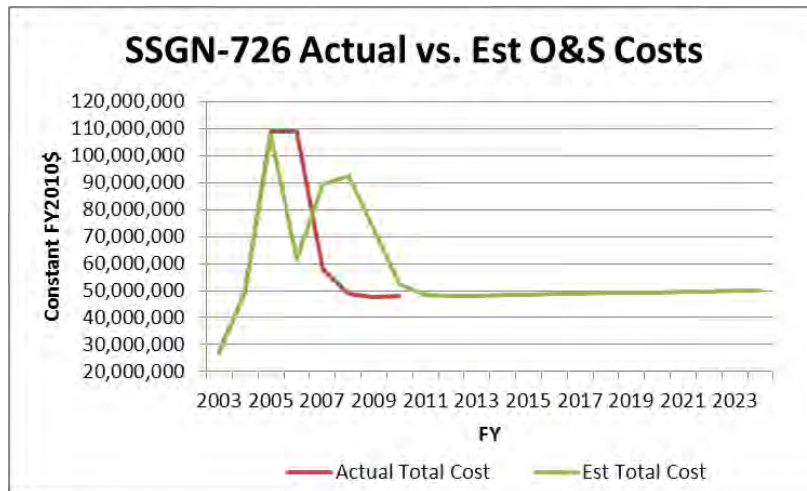


Figure 28. Testing and Projection of SSGN-726 Regression Model

FY	Actual Total Cost	Est Total Cost	Variance	Variance %
2003	27,073,340	26,726,990	-346,350	-1.3%
2004	49,276,238	49,522,222	245,984	0.5%
2005	109,087,529	107,776,117	-1,311,412	-1.2%
2006	108,848,480	61,683,582	-47,164,898	-43.3%
2007	57,993,244	89,391,769	31,398,525	54.1%
2008	48,929,228	92,586,977	43,657,749	89.2%
2009	47,764,923	73,076,706	25,311,783	53.0%
2010	47,852,794	52,296,283	4,443,489	9.3%
AVERAGE			11,529,329	32.5%

Table 13. SSGN-726 O&S Cost Variances

## 12. America Class Amphibious Ship (LHA-6)

With the intent of replacing the older Tarawa class ships (LHA-1), the first of the new America class amphibious ships is currently scheduled for delivery to the Navy in late FY2013. A point estimate was used for future cost estimating based on the SAR O&S data shown in Figure 29. Total O&S costs were estimated to be \$123.3M per ship

which served as the amount used in FY2024 as well. Of note, unlike the DDG-1000 in which maintenance costs were the most expensive, in this particular case, manpower costs consumed the most costs.

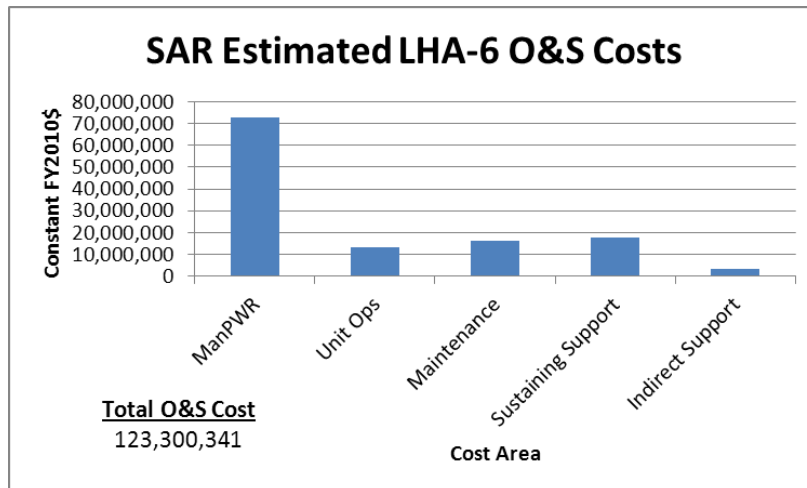


Figure 29. LHA-6 Costs by Area Based on SAR Report

### 13. Wasp Class Amphibious Ship (LHD-1)

When stretched over the 20 years, the O&S costs incurred by the Wasp class ships have increased gradually, essentially doubling throughout this time. With a recorded low of \$78.6M in total actual costs in FY1993 to a high of \$158.4 as current as FY2010, these increases, shown in Figure 30 were contributed rather equally by both manning and maintenance costs when comparing through ratios.

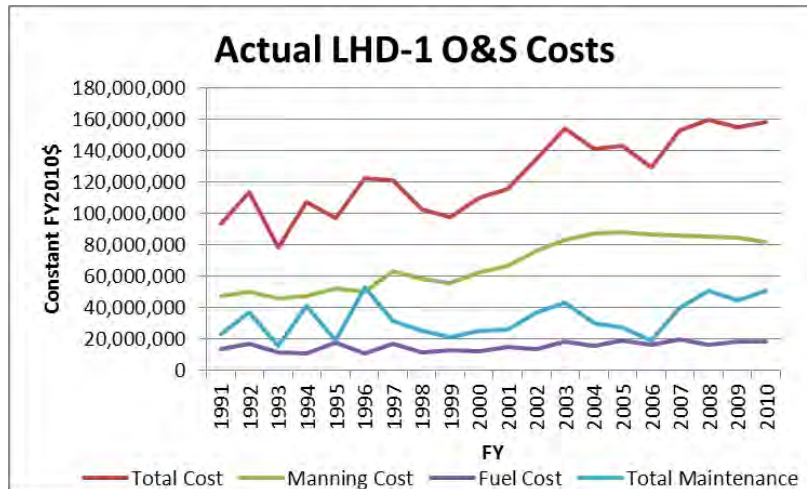


Figure 30. LHD-1 Costs by Top Three Cost Drivers

$$\begin{aligned} \text{Total LHD-1 O\&S Cost} &= b_0 + b_1\text{MPC} + b_2\text{FC} + b_3\text{MC} + E \\ &= b_0 + b_1(b_4 + b_5\text{FY} + b_6\text{EL\#}) + b_2\text{FC} + b_3\text{MC} + E \end{aligned}$$

Where,

$B_{0-6}$  = Coefficients, E= Error

MPC, FC, MC = Manpower, Fuel, and Maintenance Costs respectively

FY and EL# = Fiscal Year and Enlisted#

A comparison of the results of the regression equation with the actual O&S costs recorded over the last 20 years was completed. As shown in Figure 31, the future costs estimates (Est Total Cost) line followed fairly well to the actual costs line. Based on its continued trajectory, there was some warrant for concern over extremely high cost growths in the future even when considering the tendency that these estimates were underestimated by a mean of 1.3 percent as Table 14 shows. Using this model for future predictions yielded an O&S cost in FY2024 of \$196.5M per ship which was a 24 percent growth from its FY2010 actual recorded cost of \$158.4M.

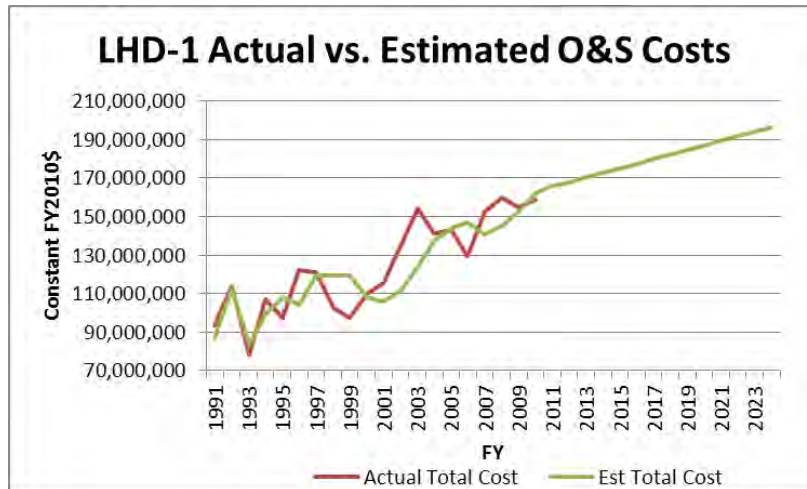


Figure 31. Testing and Projection of LHD-1 Regression Model

FY	Actual Total Cost	Est Total Cost	Variance	Variance %
1991	93,255,774	86,667,117	-6,588,657	-7.1%
1992	113,470,368	112,422,887	-1,047,481	-0.9%
1993	78,602,261	83,472,376	4,870,115	6.2%
1994	107,028,172	98,952,885	-8,075,287	-7.5%
1995	97,221,492	108,252,834	11,031,342	11.3%
1996	122,130,317	104,431,923	-17,698,394	-14.5%
1997	120,969,728	119,462,913	-1,506,815	-1.2%
1998	102,452,279	119,598,133	17,145,854	16.7%
1999	97,559,748	119,505,076	21,945,328	22.5%
2000	109,903,727	108,143,245	-1,760,482	-1.6%
2001	115,435,945	105,899,159	-9,536,786	-8.3%
2002	134,662,729	111,591,232	-23,071,497	-17.1%
2003	154,274,603	124,049,323	-30,225,280	-19.6%
2004	141,212,593	137,386,418	-3,826,175	-2.7%
2005	142,808,161	144,320,571	1,512,410	1.1%
2006	129,279,641	146,954,845	17,675,204	13.7%
2007	152,348,884	140,547,567	-11,801,317	-7.7%
2008	159,810,699	145,160,243	-14,650,456	-9.2%
2009	154,931,734	152,217,325	-2,714,409	-1.8%
2010	158,401,471	161,941,476	3,540,005	2.2%
AVERAGE			-2,739,139	-1.3%

Table 14. LHD-1 O&S Cost Variances

#### 14. San Antonio Class Amphibious Ship (LPD-17)

The San Antonio class ship is a fairly young platform with four years of cost data available. As such, little changes to cost profiles were observed but instead reflect steady costs for all three categories, shown in Figure 32. Since the lack of data years prevented a possible regression model from being calculated, a three-year moving average model was used for future cost estimates instead.

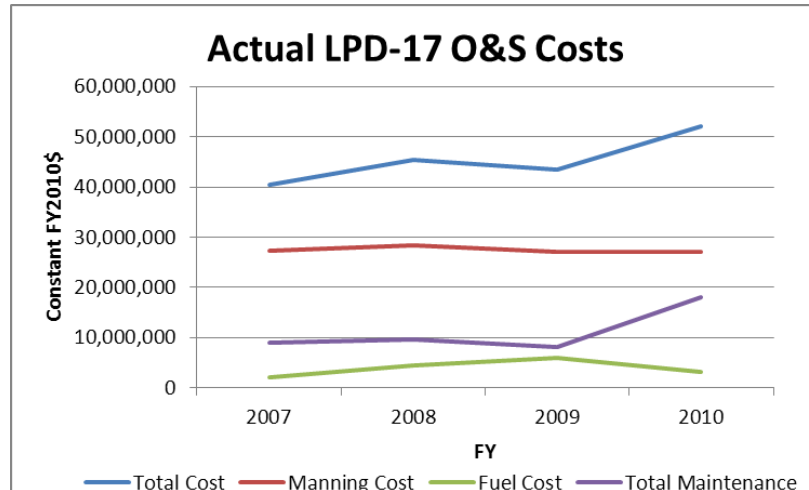


Figure 32. LPD-17 Costs by Top Three Cost Drivers

A comparison of the results of the averaging model with the actual O&S costs recorded over the last four years was completed and Figure 33 and Table 15 show the comparison of the two. Using this model yielded an O&S cost in FY2024 of \$48M per ship which was an approximate 7.7 percent decrease from its FY2010 actual recorded cost of \$52.1. The decrease was based solely on the model in which little cost data were able to be used to predict a more accurate trend.

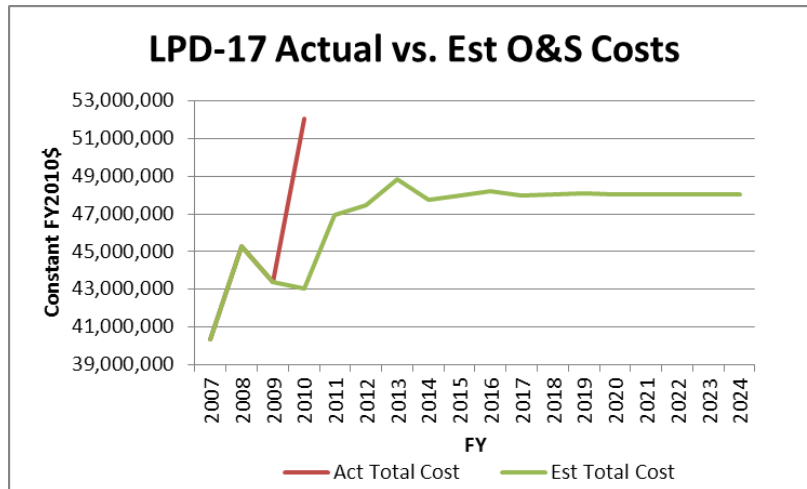


Figure 33. Testing and Projection of LPD-17 Model

FY	Actual Total Cost	Est Total Cost	Variance	Variance %
2007	40,342,796	40,342,796	0	0.0%
2008	45,287,875	45,287,875	0	0.0%
2009	43,404,896	43,404,896	0	0.0%
2010	52,072,032	43,011,856	-9,060,176	-17.4%
AVERAGE			-2,265,044	-4.3%

Table 15. LPD-17 O&S Cost Variances

## 15. Whidbey Island Class Amphibious Ship (LSD-41)

In Figure 34, the upward trend in O&S costs was very noticeable, growing from initially just under \$30.1M to the later \$82.7M in the 20 years observed. It is worth mentioning that although manning costs were higher than fuel and maintenance costs during most of this time, beginning in FY2009 and into FY2010, maintenance costs finally surpassed manning costs.

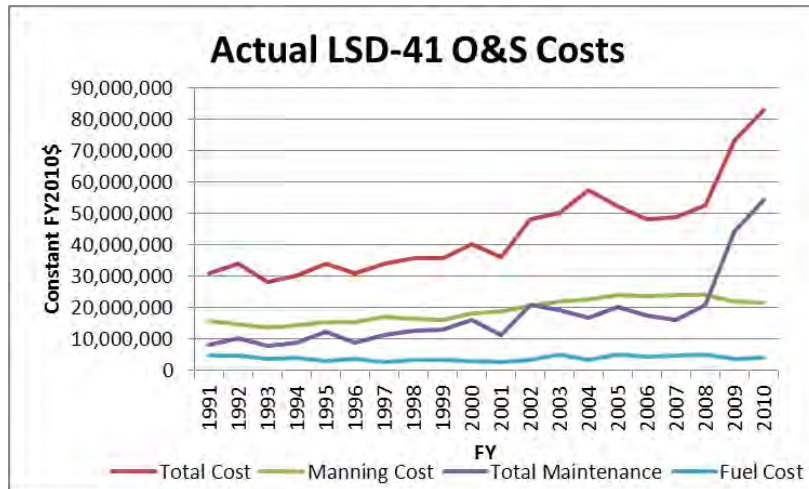


Figure 34. LSD-41 Costs by Top Three Cost Drivers

$$\begin{aligned} \text{Total LSD-41 O\&S Cost} &= b_0 + b_1\text{MPC} + b_2\text{MC} + E \\ &= b_0 + b_1(b_3 + b_4\text{FY} + b_5\text{MP\#}) + b_2\text{MC} + E \end{aligned}$$

Where,

$B_{0-5}$  = Coefficients,  $E$ = Error

MPC and MC = Manpower and Maintenance Costs respectively

FY and MP# = Fiscal Year and Manpower #

A comparison of the results of the regression model with the actual O&S costs recorded over the last 20 years was completed. Figure 35 and Table 16 show the comparison of the two in which the model tended to underestimate the actual costs by 5.2 percent. Despite the actual costs tripling over the last 20 years, the model only predicted a future growth of four percent. That is to say, it yielded an O&S cost in FY2024 of \$86M per ship compared to its FY2010 actual recorded cost of \$82.7M.

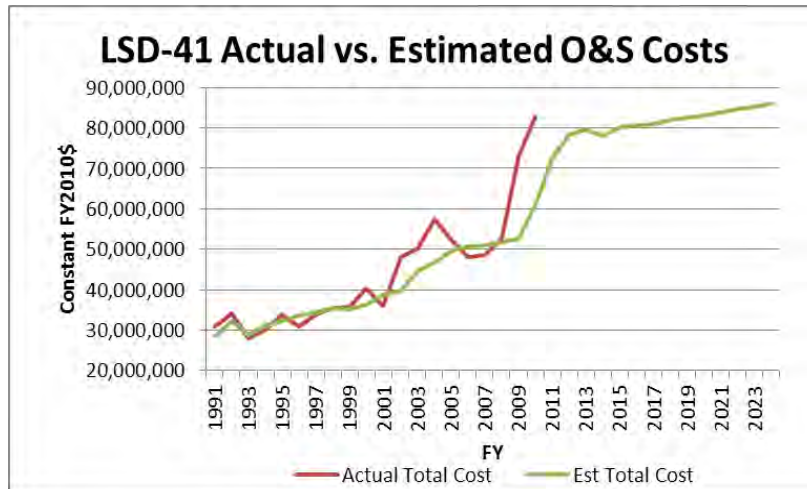


Figure 35. Testing and Projection of LSD-41 Regression Model

FY	Actual Total Cost	Est Total Cost	Variance	Variance %
1991	30,910,357	28,407,623	-2,502,734	-8.1%
1992	34,085,463	32,375,312	-1,710,151	-5.0%
1993	28,002,957	28,910,270	907,313	3.2%
1994	30,091,046	31,289,401	1,198,355	4.0%
1995	33,828,381	32,375,896	-1,452,485	-4.3%
1996	31,050,578	33,554,707	2,504,129	8.1%
1997	33,967,077	34,479,889	512,812	1.5%
1998	35,550,462	35,374,989	-175,473	-0.5%
1999	35,689,105	35,208,896	-480,209	-1.3%
2000	40,169,796	36,265,260	-3,904,536	-9.7%
2001	35,983,318	38,587,746	2,604,428	7.2%
2002	48,055,530	39,634,031	-8,421,499	-17.5%
2003	50,072,488	44,511,145	-5,561,343	-11.1%
2004	57,282,904	46,796,656	-10,486,248	-18.3%
2005	52,347,871	49,771,795	-2,576,076	-4.9%
2006	48,127,325	50,595,962	2,468,637	5.1%
2007	48,642,435	51,073,838	2,431,403	5.0%
2008	52,661,195	51,753,504	-907,691	-1.7%
2009	73,057,255	52,466,320	-20,590,935	-28.2%
2010	82,745,203	60,860,615	-21,884,588	-26.4%
AVERAGE			-3,401,345	-5.2%

Table 16. LSD-41 O&S Cost Variances

## 16. Harpers Ferry Class Amphibious Ship (LSD-49)

The Harpers Ferry class of ships seemed to almost mimic the LSD-41 ships in cost profile but on a smaller scale as shown in Figure 36. It too showed signs of increasing maintenance costs to the point where they were surpassing manning costs in FY2010 just as LSD-41 maintenance costs did so in FY2009–2010. In addition, rather than tripling in costs as LSD-41 did, LSD-49 fell just short of doubling.

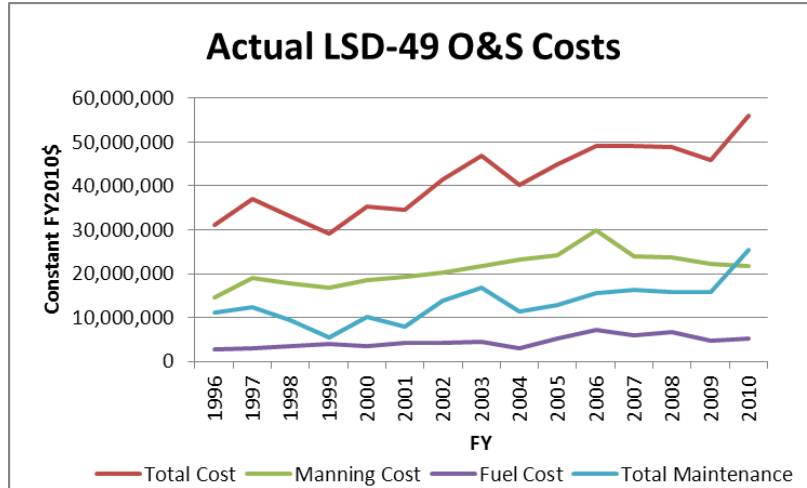


Figure 36. LSD-49 Costs by Top Three Cost Drivers

Referring to Table 38 in APPENDIX B, there was a high correlation (over .7) between the manning cost (MPC) and fuel cost (FC) independent variables within the LSD-49 regression model. Similarly to what was done with previous regression models that suffered from correlation and where additional tests/models were created without these variables, it was decided to simply ignore this correlation and still use all variables since the removing of the variables would cause a weaker model.

$$\begin{aligned} \text{Total LSD-49 O\&S Cost} &= b_0 + b_1\text{MPC} + b_2\text{FC} + b_3\text{MC} + E \\ &= b_0 + b_1\text{MPC} + b_2(b_4 + b_5\$GAL + b_6\text{HRSUW}) + b_3\text{MC} + E \end{aligned}$$

Where,

$B_{0-6}$  = Coefficients, E= Error

MPC, FC, MC = Manpower, Fuel, and Maintenance Costs respectively

\$GAL and HRSUW = Price/Gallon Fuel and Steaming Hours Underway

A comparison of the results of the regression model with the actual O&S costs recorded over the last 15 years was completed. Figure 37 and Table 17 show the comparison of the two in which the model tended to underestimate actual costs by 4.1 percent. Despite the actual costs nearly doubling during this time, the regression model predicted a relatively steady O&S cost amount leading up to FY2024. That is to say, using this model yielded an O&S cost in FY2024 of \$51.4 per ship compared to its FY2010 actual recorded cost of \$56M. This decrease in costs could possibly be explained by the decrease in manning numbers over time which has ranged from a low of 293 in FY2009 to a high of 356 in FY2004 with 308 as the average into the future.

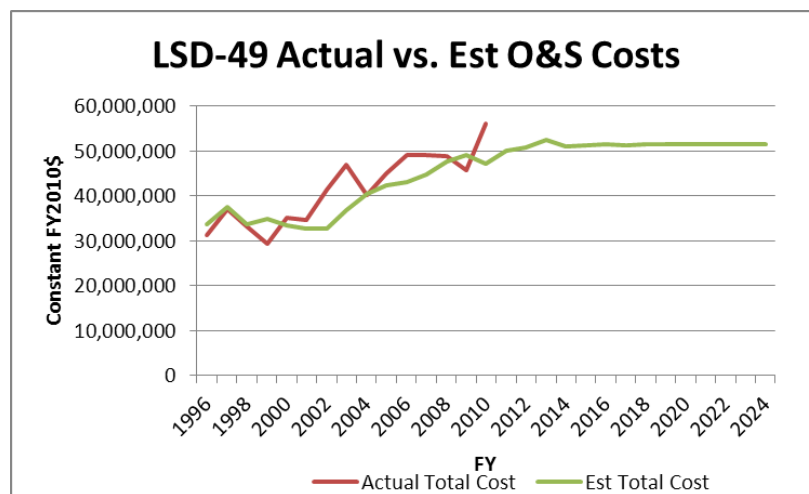


Figure 37. Testing and Projection of LSD-49 Regression Model

<b>FY</b>	<b>Actual Total Cost</b>	<b>Est Total Cost</b>	<b>Variance</b>	<b>Variance %</b>
1996	31,196,015	33,645,878	2,449,863	7.9%
1997	37,025,347	37,520,594	495,247	1.3%
1998	33,147,313	33,594,805	447,492	1.4%
1999	29,236,291	34,920,426	5,684,135	19.4%
2000	35,204,844	33,406,641	-1,798,203	-5.1%
2001	34,651,227	32,592,293	-2,058,934	-5.9%
2002	41,425,869	32,617,290	-8,808,579	-21.3%
2003	46,928,096	36,705,907	-10,222,189	-21.8%
2004	40,207,244	40,486,230	278,986	0.7%
2005	44,979,907	42,425,674	-2,554,233	-5.7%
2006	49,197,734	43,147,320	-6,050,414	-12.3%
2007	49,087,273	44,816,364	-4,270,909	-8.7%
2008	48,896,558	47,694,801	-1,201,757	-2.5%
2009	45,802,188	49,178,984	3,376,796	7.4%
2010	55,982,479	47,224,352	-8,758,127	-15.6%
AVERAGE			-2,199,388	-4.1%

Table 17. LSD-49 O&S Cost Variances

#### **17. Unnamed Future Class Amphibious Ship (LSD-X)**

Scheduled to begin replacing the LSD-41 ships in FY2017, there currently are no acquisition data available or SAR report for the new LSD-X.<sup>37</sup> With two ships expected to be commissioned into the fleet before FY2024, the cost estimate used in its place was an analogous one drawn from the cost data used in the LSD-49 platform. Therefore an estimated O&S cost of \$51.4M (same as LSD-49) was used for FY2024.

#### **18. Avenger Class Mine Counter Measures Ship (MCM-1)**

Despite the new Littoral Combat Ships (LCS) joining the ranks within the battle force, the mine counter measure ships still have a future well into FY2024. The cost profile broken into its top three cost drivers illustrated in Figure 38 shows a very steady cost trend during this last decade.

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<sup>37</sup> Per OPNAV N8F's "Report to Congress on Annual Long-Range Plan for Construction of Naval Vessels for FY2011."

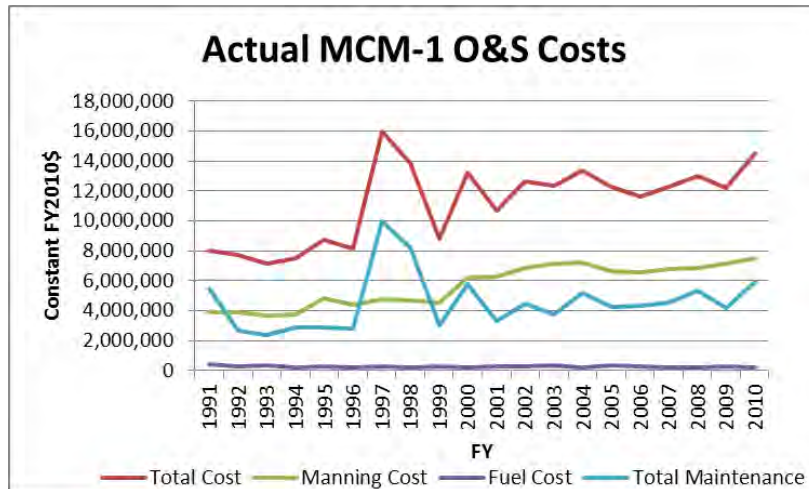


Figure 38. MCM-1 Costs by Top Three Cost Drivers

$$\begin{aligned} \text{Total MCM-1 O\&S Cost} &= b_0 + b_1\text{MPC} + b_2\text{MC} + E \\ &= b_0 + b_1(b_3 + b_4\text{FY} + b_5\text{MP\#}) + b_2\text{MC} + E \end{aligned}$$

Where,

$B_{0-5}$  = Coefficients, E= Error

MPC and MC = Manpower and Maintenance Costs respectively

FY and MP# = Fiscal Year and Manpower #

A comparison of the results of the regression model with the actual O&S costs recorded over the last 20 years was completed and Figure 39 and Table 18 show the comparison of the two. Using this model for future predictions yielded an O&S cost in FY2024 of \$17.6M per ship which was a 21.4 percent growth from the FY2010 actual recorded cost of \$14.5M.

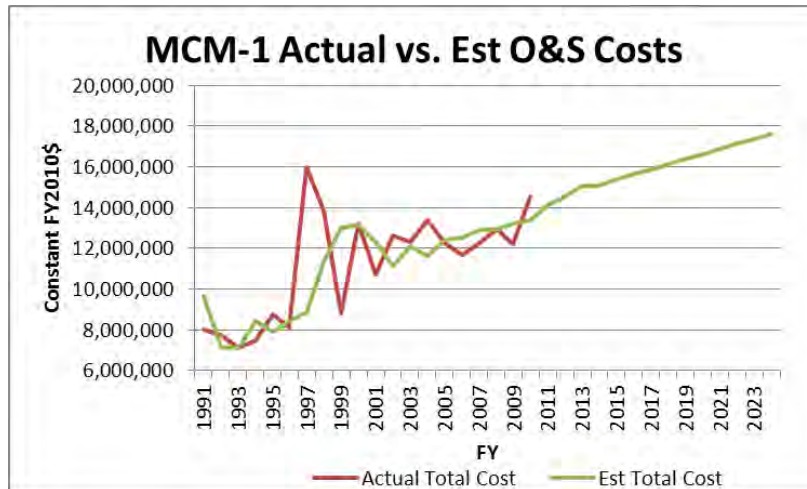


Figure 39. Testing and Projection of MCM-1 Regression Model

<b>FY</b>	<b>Actual Total Cost</b>	<b>Est Total Cost</b>	<b>Variance</b>	<b>Variance %</b>
1991	8,001,840	9,654,737	1,652,897	20.7%
1992	7,716,604	7,144,786	-571,818	-7.4%
1993	7,109,935	7,085,188	-24,747	-0.3%
1994	7,493,133	8,458,748	965,615	12.9%
1995	8,749,312	7,888,336	-860,976	-9.8%
1996	8,128,919	8,436,578	307,659	3.8%
1997	15,974,833	8,877,712	-7,097,121	-44.4%
1998	13,846,321	11,368,486	-2,477,835	-17.9%
1999	8,808,692	13,017,745	4,209,053	47.8%
2000	13,234,992	13,174,537	-60,455	-0.5%
2001	10,707,833	12,293,937	1,586,104	14.8%
2002	12,642,881	11,128,676	-1,514,205	-12.0%
2003	12,323,412	12,082,268	-241,144	-2.0%
2004	13,350,602	11,594,694	-1,755,908	-13.2%
2005	12,244,138	12,392,190	148,052	1.2%
2006	11,649,775	12,502,473	852,698	7.3%
2007	12,260,826	12,874,006	613,180	5.0%
2008	12,957,838	12,958,060	222	0.0%
2009	12,216,428	13,188,507	972,079	8.0%
2010	14,515,803	13,371,297	-1,144,506	-7.9%
AVERAGE			258,735	2.5%

Table 18. MCM-1 O&S Cost Variances

## 19. Dry Cargo and Ammunition Ship (AKE-1)

As Figure 40 shows, this class of ship is a young platform with only four years of cost data available. As a result, a three-year moving average served as the cost estimating model.

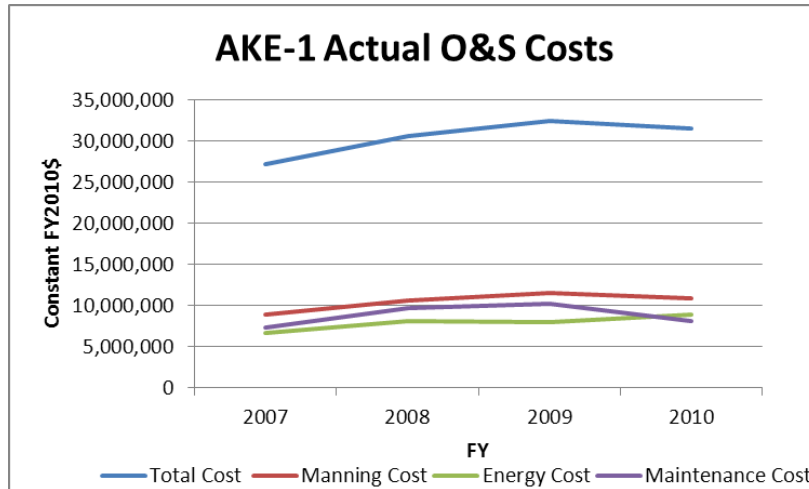


Figure 40. AKE-1 Costs by Top Three Cost Drivers

A comparison of the results of the averaging model with the actual O&S costs recorded over the last few years was completed and Figure 41 and Table 19 show the comparison of the two. Using this model for future predictions yielded an O&S cost in FY2024 of \$31.7M per ship which was a negligible increase from the FY2010 actual recorded cost of \$31.6.

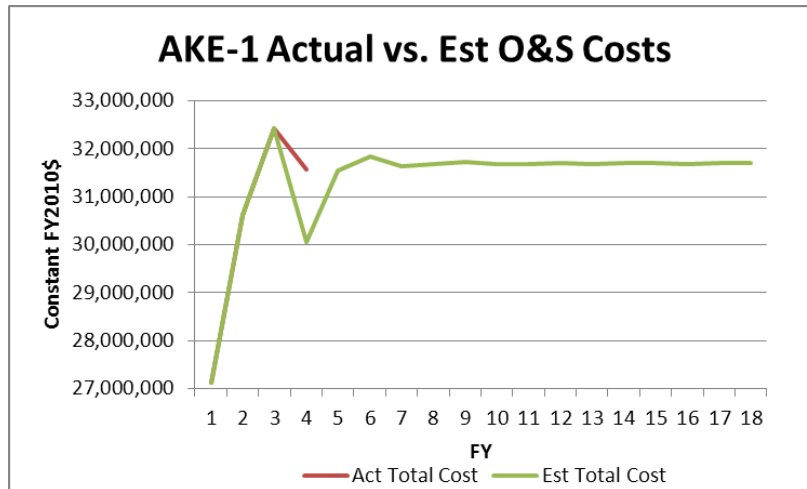


Figure 41. Testing and Projection of AKE-1 Model

FY	Actual Total Cost	Est Total Cost	Variance	Variance %
2007	27,126,405	27,126,405	0	0.0%
2008	30,629,707	30,629,707	0	0.0%
2009	32,421,493	32,421,493	0	0.0%
2010	31,566,762	30,059,202	-1,507,560	-4.8%
AVERAGE			-376,890	-1.2%

Table 19. AKE-1 O&S Cost Variances

## 20. Oiler Ship (AO-187)

One might think after reviewing Figure 42 that actual and estimated costs would result in near perfect numbers since all three cost drivers appeared to be steady. However when zoomed further in as is done in Figure 43, there was quite a lot of volatility, even if on a smaller scale when compared to other platforms.

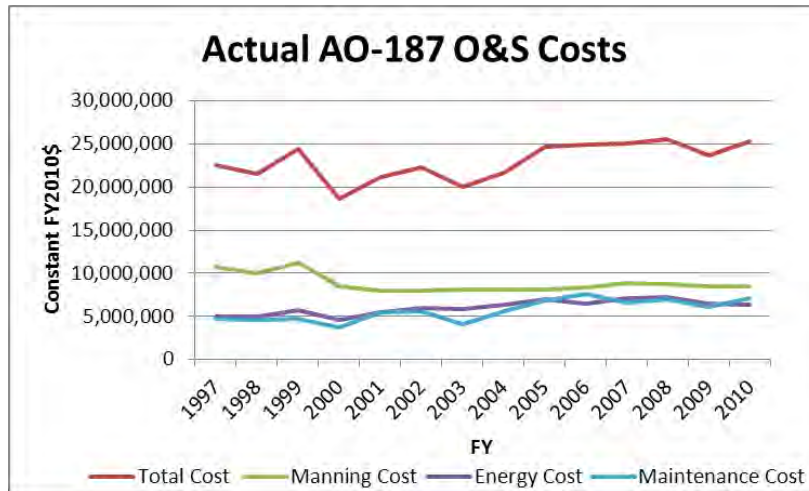


Figure 42. AO-187 Costs by Top Three Cost Drivers

$$\begin{aligned} \text{Total AO-187 O\&S Cost} &= b_0 + b_1\text{MPC} + b_2\text{EC} + b_3\text{MC} + E \\ &= b_0 + b_1\text{MPC} + b_2\text{EC} + b_3\text{MC} + E \end{aligned}$$

Where,

$B_{0-3}$  = Coefficients,  $E$  = Error

MPC, EC, MC = Manpower, Energy (Fuel) and Maintenance Costs respectively

Referring to Table 40 in APPENDIX B, there was a high correlation (over .7) between the energy cost (EC) and maintenance cost (MC) independent variables within the regression model. Following suit from other models, this was ignored since changes were negligible.

A comparison of the results of the regression model with the actual O&S costs recorded over the last 14 years was completed. Figure 43 and Table 20 show the comparison of the two in which the model tended to underestimate cost by 2.2 percent on average. Using this model for future predictions yielded an O&S cost in FY2024 of \$24.5M per ship which was a four percent decrease from the FY2010 actual recorded

cost of \$25.4M. This decrease was assumed to be driven by the model in which all three cost drivers were relatively steady at \$25M or under in actual costs.

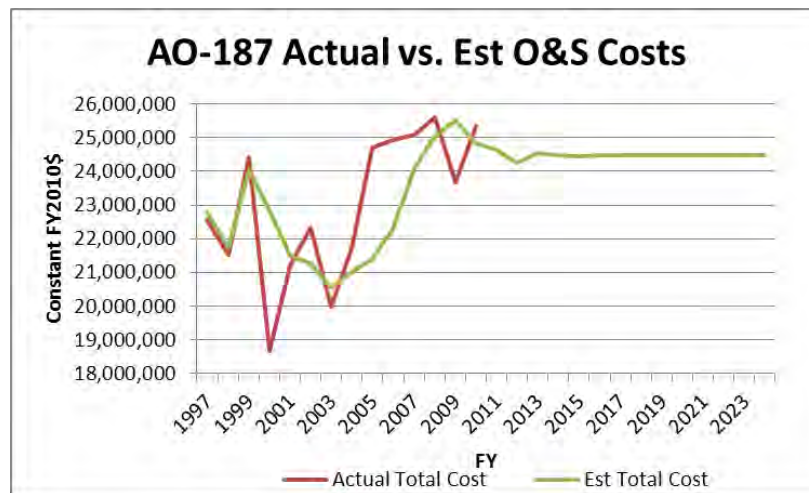


Figure 43. Testing and Projection of AO-187 Regression Model

FY	Actual Total Cost	Est Total Cost	Variance	Variance %
1997	22,538,063	22,789,036	250,973	1.1%
1998	21,513,716	21,747,448	233,732	1.1%
1999	24,406,590	24,019,417	-387,173	-1.6%
2000	18,664,307	22,851,967	4,187,660	22.4%
2001	21,198,112	21,479,732	281,620	1.3%
2002	22,324,804	21,284,034	-1,040,771	-4.7%
2003	19,991,436	20,557,860	566,424	2.8%
2004	21,705,433	21,004,244	-701,189	-3.2%
2005	24,689,485	21,395,016	-3,294,470	-13.3%
2006	24,915,940	22,283,608	-2,632,333	-10.6%
2007	25,103,526	24,086,144	-1,017,382	-4.1%
2008	25,617,471	25,063,099	-554,373	-2.2%
2009	23,679,539	25,495,353	1,815,814	7.7%
2010	25,362,523	24,826,444	-536,079	-2.1%
AVERAGE			-584,870	-2.2%

Table 20. AO-187 O&S Cost Variances

## 21. Fast Combat Support Ship (AOE-6)

The cost profiles for the Fast Combat Support Ships showed a significant increase from FY2001 to FY2006 before declining back downward as seen in Figure 44. A possible explanation for this was simply due to the four ships in its class being employed

less towards the later part of the decade, which happened to coincide with a projected winding down of military operations within the Arabian Gulf region.

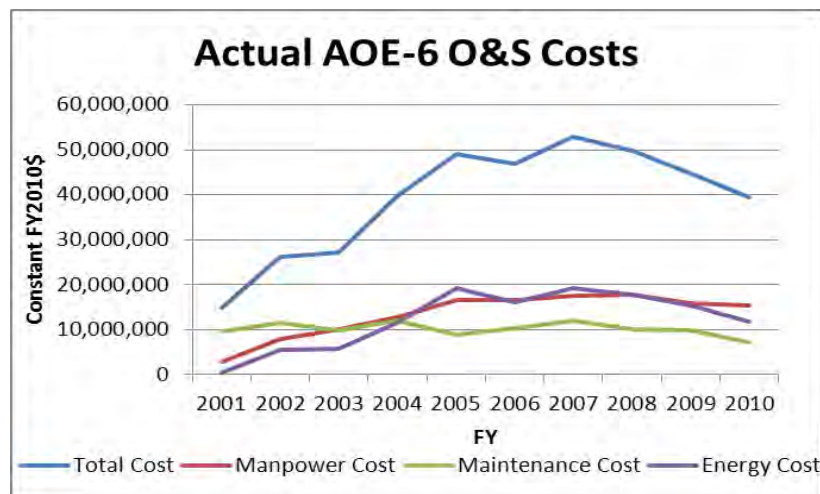


Figure 44. Costs by Top Three Cost Drivers

Referring to Table 41 in APPENDIX B, there was a high correlation (over .7) between the manpower cost (MC) and maintenance cost (MC) independent variables within the regression model. Following suit from previous models, this was ignored since changes were negligible.

$$\begin{aligned} \text{Total AOE-6 O\&S Cost} &= b_0 + b_1\text{MPC} + b_2\text{EC} + b_3\text{MC} + E \\ &= b_0 + b_1\text{MPC} + b_2(b_4 + b_5\$GAL + b_6\text{HRSUW}) + b_3\text{MC} + E \end{aligned}$$

Where,

$B_{0-6}$  = Coefficients, E= Error

MPC, EC, MC = Manpower, Energy (Fuel), and Maintenance Costs respectively

$\$GAL$  and  $HRSUW$  = Price/Gallon Fuel and Steaming Hours Underway

A comparison of the results of the regression model with the actual O&S costs recorded over the last 10 years was completed. Figure 45 and Table 21 show the comparison of the two in which the model, on average, underestimated the actual costs by

16.2 percent. Using this model for future predictions yielded an O&S cost in FY2024 of \$37M per ship which was a six percent decrease from the FY2010 actual recorded cost of \$39.5M. This decrease was assumed to be driven by the model in which all three recorded actual cost areas were trending back downward.

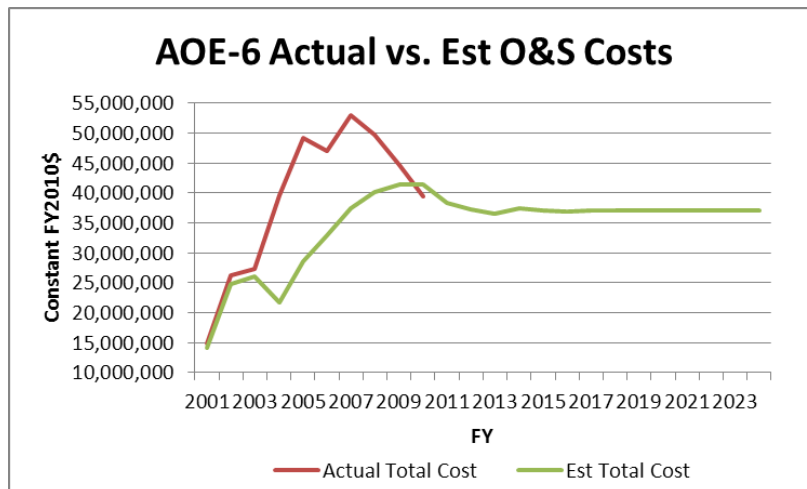


Figure 45. Testing and Projection of AOE-6 Regression Model

FY	Actual Total Cost	Est Total Cost	Variance	Variance %
2001	14,786,355	14,056,820	-729,535	-4.9%
2002	26,216,835	24,840,170	-1,376,664	-5.3%
2003	27,250,460	26,048,170	-1,202,289	-4.4%
2004	39,674,674	21,647,454	-18,027,219	-45.4%
2005	49,094,832	28,493,032	-20,601,800	-42.0%
2006	46,929,630	32,953,827	-13,975,803	-29.8%
2007	52,871,334	37,330,150	-15,541,185	-29.4%
2008	49,748,491	40,127,150	-9,621,341	-19.3%
2009	44,674,035	41,321,280	-3,352,755	-7.5%
2010	39,479,782	41,409,963	1,930,182	4.9%
AVERAGE			-8,112,180	-16.2%

Table 21. AOE-6 O&S Cost Variances

## 22. Blue Ridge Class Command Ship (LCC-19)

The only two Blue Ridge class command ships in the battle force inventory have already reached their 40 year mark in terms of service in the fleet and are currently scheduled to remain a part of it into FY2024. As Figure 46 illustrates, this aging platform

has suffered from significant maintenance cost spikes throughout the years and will probably continue to worsen as it gets older.

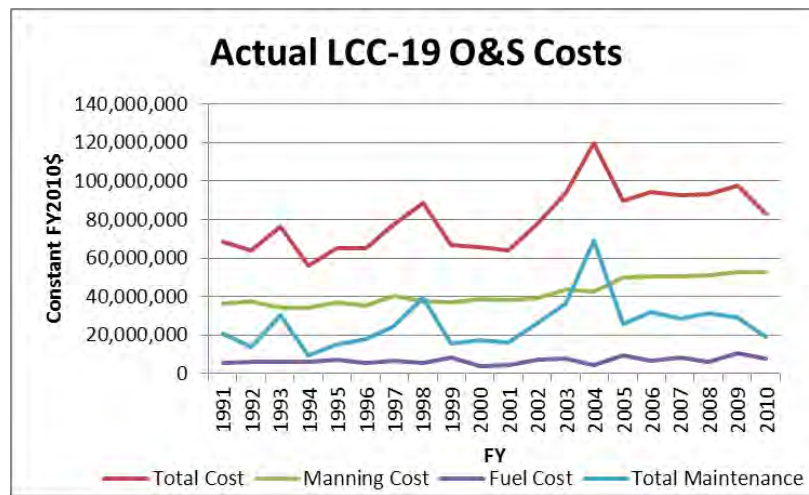


Figure 46. LCC-19 Costs by Top Three Cost Drivers

$$\begin{aligned} \text{Total LCC-19 O\&S Cost} &= b_0 + b_1\text{MPC} + b_2\text{FC} + b_3\text{MC} + E \\ &= b_0 + b_1(b_4 + b_5\text{FY} + b_6\text{MP\#}) + b_2\text{FC} + b_3\text{MC} + E \end{aligned}$$

Where,

$B_{0-6}$  = Coefficients, E= Error

MPC, FC, MC = Manpower, Fuel, and Maintenance Costs respectively

FY and MP# = Fiscal Year and Manpower #

A comparison of the results of the regression model against the actual O&S costs recorded over the last 20 years was completed and Figure 47 and Table 22 show the comparison of the two. Using this model for future predictions yielded an O&S cost in FY2024 of \$109.4M per ship which was a 32 percent increase from the FY2010 actual recorded cost of \$82.8M. This significant increase was assumed to be driven by the increasingly larger maintenance fluctuations experienced over the last two decades of

which was expected to continue as this class of ships' service life is extended beyond fifty years of service as it enters FY2024.

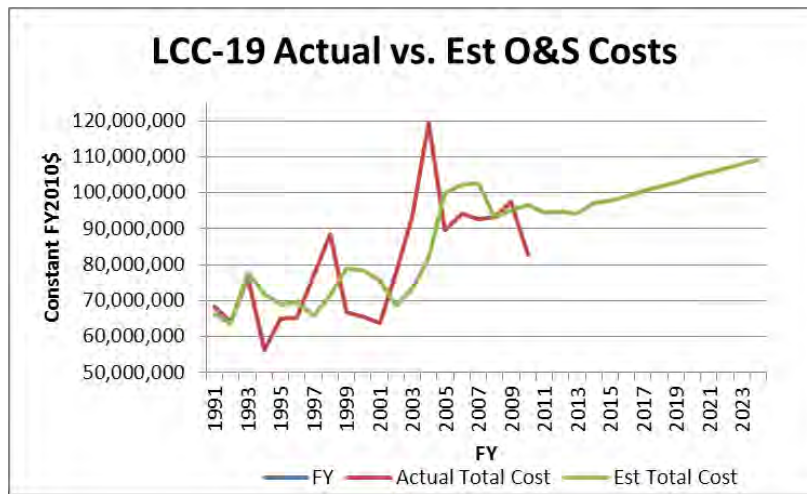


Figure 47. Testing and Projection of LCC-19 Regression Model

<b>FY</b>	<b>Actual Total Cost</b>	<b>Est Total Cost</b>	<b>Variance</b>	<b>Variance %</b>
1991	68,242,478	66,257,769	-1,984,709	-2.9%
1992	64,188,885	63,596,336	-592,549	-0.9%
1993	76,420,527	77,814,131	1,393,604	1.8%
1994	56,131,594	71,778,359	15,646,765	27.9%
1995	64,935,896	68,942,589	4,006,693	6.2%
1996	65,229,250	69,454,968	4,225,718	6.5%
1997	77,376,091	65,921,869	-11,454,222	-14.8%
1998	88,535,510	71,555,502	-16,980,008	-19.2%
1999	66,662,749	78,824,696	12,161,947	18.2%
2000	65,477,288	78,523,705	13,046,417	19.9%
2001	63,693,458	75,536,380	11,842,922	18.6%
2002	77,885,079	68,654,425	-9,230,654	-11.9%
2003	93,690,168	73,313,509	-20,376,659	-21.7%
2004	119,372,689	81,899,599	-37,473,090	-31.4%
2005	89,561,808	100,017,870	10,456,062	11.7%
2006	94,251,405	102,428,837	8,177,432	8.7%
2007	92,709,267	102,724,612	10,015,345	10.8%
2008	93,199,944	93,277,838	77,894	0.1%
2009	97,405,960	95,056,413	-2,349,547	-2.4%
2010	82,814,300	96,750,342	13,936,042	16.8%
AVERAGE			227,270	2.1%

Table 22. LCC-19 O&S Cost Variances

### 23. Submarine Tender Ship (AS-39)

As the “Manning cost” line in Figure 48 shows, manning costs have dominated the total O&S costs incurred by the submarine tender ships, increasing from approximately \$56M to \$90M while fuel and maintenance costs remained comparatively low.

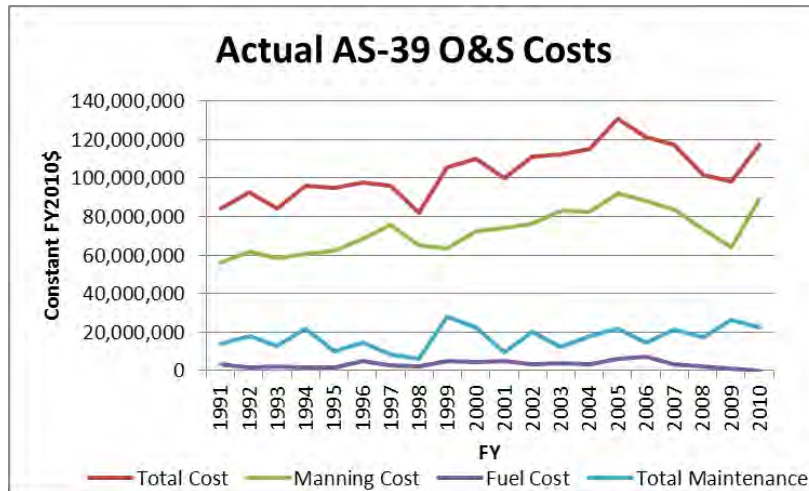


Figure 48. AS-39 Costs by Top Three Cost Drivers

$$\begin{aligned} \text{Total AS-39 O\&S Cost} &= b_0 + b_1\text{MPC} + b_2\text{FC} + b_3\text{MC} + E \\ &= b_0 + b_1\text{MPC} + b_2\text{FC} + b_3\text{MC} + E \end{aligned}$$

Where,

$B_{0-3}$  = Coefficients, E= Error

MPC, FC, MC = Manpower, Fuel and Maintenance Costs respectively

A comparison of the results of the regression model with the actual O&S costs recorded over the last 20 years was completed. Figure 49 and Table 23 show the comparison of the two in which the model tended to overestimate costs by an average of 5.7 percent. Using this model for future predictions yielded an O&S cost in FY2024 of \$110.5M per ship which was a 5.7 percent decrease from the FY2010 actual recorded cost of \$117.2M. This decrease was assumed to be driven by the over \$2M decrease in fuel costs during the last two years observed.

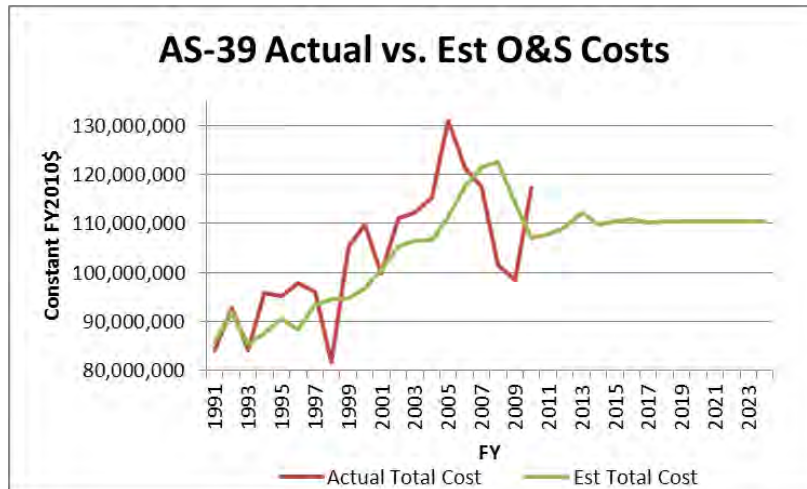


Figure 49. Testing and Projection of AS-39 Regression Model

FY	Actual Total Cost	Est Total Cost	Variance	Variance %
1991	84,043,466	85,878,164	1,834,698	2.2%
1992	92,825,765	91,864,470	-961,295	-1.0%
1993	84,134,230	85,187,014	1,052,784	1.3%
1994	95,744,616	87,643,216	-8,101,400	-8.5%
1995	95,123,558	90,477,270	-4,646,288	-4.9%
1996	97,878,205	88,359,592	-9,518,613	-9.7%
1997	95,998,567	93,329,073	-2,669,494	-2.8%
1998	81,811,358	94,587,718	12,776,360	15.6%
1999	105,342,426	94,785,408	-10,557,018	-10.0%
2000	109,826,106	96,799,758	-13,026,348	-11.9%
2001	99,757,916	100,491,692	733,776	0.7%
2002	111,164,145	105,334,783	-5,829,362	-5.2%
2003	112,268,101	106,338,555	-5,929,546	-5.3%
2004	115,258,168	106,727,394	-8,530,774	-7.4%
2005	130,845,752	111,250,297	-19,595,455	-15.0%
2006	121,142,846	117,800,837	-3,342,009	-2.8%
2007	117,533,430	121,554,070	4,020,640	3.4%
2008	101,666,094	122,593,892	20,927,798	20.6%
2009	98,469,511	114,166,343	15,696,832	15.9%
2010	117,239,991	107,006,359	-10,233,632	-8.7%
AVERAGE			5,413,926	5.7%

Table 23. AS-39 O&S Cost Variances

## 24. Spearhead Class High Speed Vessel (JHSV-1)

No actual historical cost data have been made available yet for the Joint High Speed Vessel so a point estimate was used in its place. The breakdown of O&S costs are

shown in Figure 50 with total O&S costs estimated to be \$27.7M per ship according to its SAR report. This was the amount used in FY2024. Of note, unlike both the DDG-1000 and the LHA-6 ships, unit operations were expected to drive most costs for this particular platform.

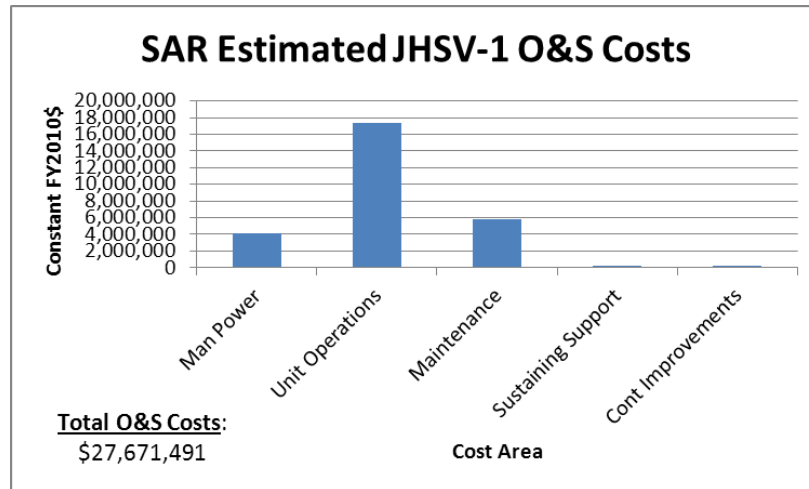


Figure 50. JHSV-1 Costs by Area Based on SAR Report

## 25. Surveillance Ship (AGOS-19)

With a crew size of about 19, one would expect the manning costs on the surveillance ships to at least top \$1M, yet as Figure 51 shows, manning costs are almost nothing. In fact, the total recorded manning costs have ranged from \$21K in FY2000 to \$41K in FY2010. That equated to an annual cost/payment of between \$1.1K and \$1.2K per crew member which cannot be accurate. However, since these were the only data available via VAMOSC and this database was assumed to be reliable, it was used.

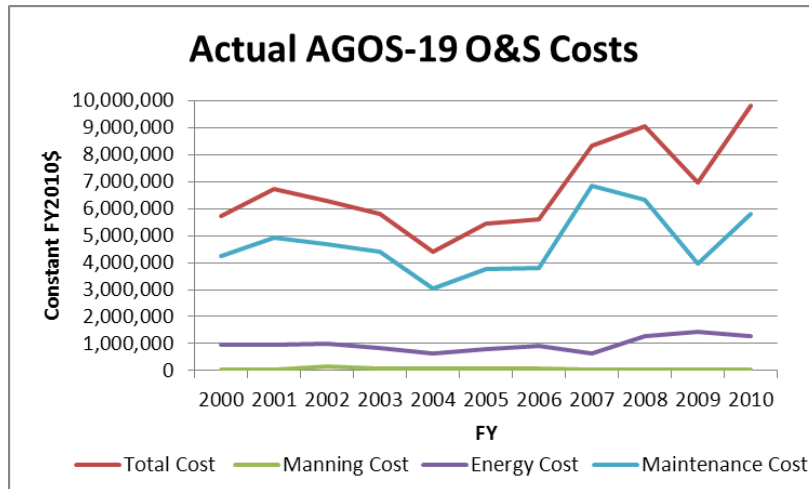


Figure 51. AGOS-19 Costs by Top Three Cost Drivers

$$\begin{aligned} \text{Total AGOS-19 O\&S Cost} &= b_0 + b_1EC + b_2MC + E \\ &= b_0 + b_1EC + b_2MC + E \end{aligned}$$

Where,

$B_{0-2}$  = Coefficients,  $E$  = Error

$EC, MC$  = Energy (Fuel) and Maintenance Costs respectively

A comparison of the results of the regression model with the actual O&S costs recorded over the last 11 years was completed. Figure 52 and Table 24 show the comparison of the two in which the model tended to underestimate costs by 17.1 percent. Using this model for future predictions yielded an O&S cost in FY2024 of \$8.3M per ship which was a 15 percent decrease from the FY2010 actual recorded cost of \$9.8M. This decrease was assumed to be driven by the low reporting of manning costs. If more reliable manning figures were used, the estimated costs would rise about \$1.5M.<sup>38</sup>

<sup>38</sup> Assuming an average annual salary of \$80K for each of the 19 crew members on board.

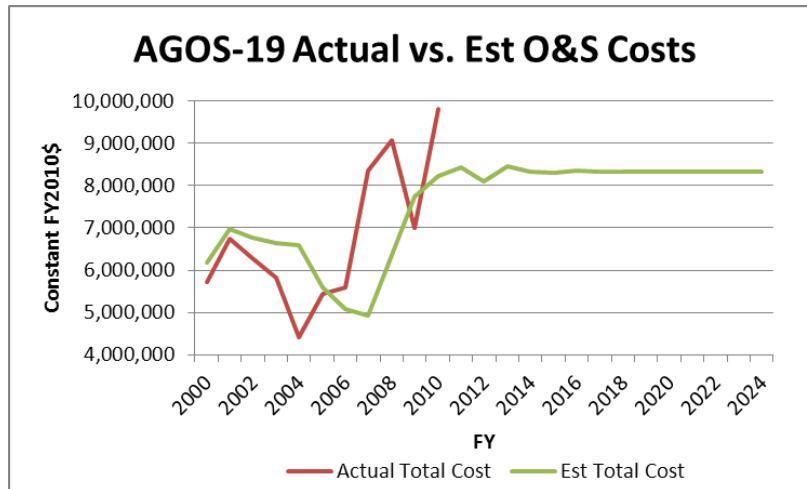


Figure 52. Testing and Projection of AGOS-19 Regression Model

FY	Actual Total Cost	Est Total Cost	Variance	Variance %
2000	5,731,108	6,179,970	448,861	7.8%
2001	6,739,755	6,980,074	240,320	3.6%
2002	6,281,975	6,780,405	498,431	7.9%
2003	5,822,766	6,646,816	824,051	14.2%
2004	4,421,055	6,601,121	2,180,066	49.3%
2005	5,442,495	5,585,715	143,220	2.6%
2006	5,592,983	5,072,058	-520,924	-9.3%
2007	8,346,710	4,916,502	-3,430,208	-41.1%
2008	9,077,969	6,367,131	-2,710,838	-29.9%
2009	6,992,669	7,746,131	753,462	10.8%
2010	9,824,173	8,235,352	-1,588,821	-16.2%
AVERAGE			-1,499,466	-17.1%

Table 24. AGOS-19 O&S Cost Variances

## 26. Surveillance Ship (AGOS-23)

Similar to the AGOS-19 surveillance ships, the AGOS-23 ships have demonstrated costs profiles in which manning costs were almost nonexistent shown in Figure 53. Despite this, regression models were used with similar future estimates to that of the AGOS-19 platform.

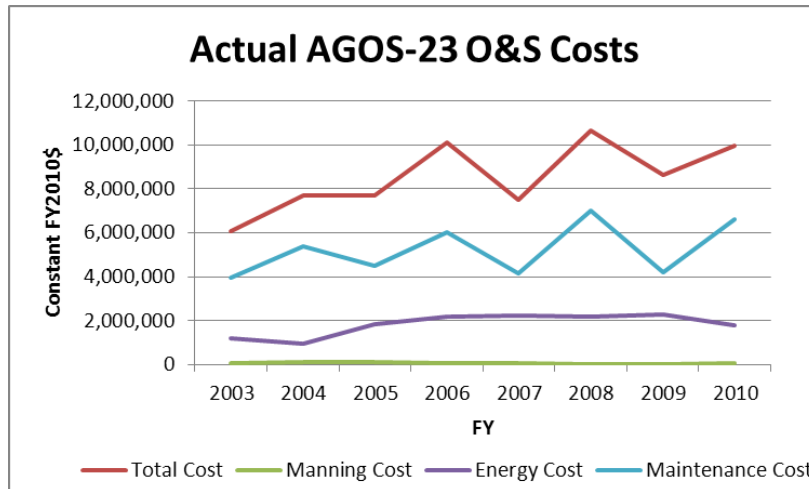


Figure 53. AGOS-23 Costs by Top Three Cost Drivers

$$\begin{aligned} \text{Total AGOS-23 O\&S Cost} &= b_0 + b_1EC + b_2MC + E \\ &= b_0 + b_1EC + b_2MC + E \end{aligned}$$

Where,

$B_{0-2}$  = Coefficients, E= Error

EC, MC = Energy (Fuel) and Maintenance Costs respectively

A comparison of the results of the regression model with the actual O&S costs recorded over the last eight years was completed. Figure 54 and Table 25 show the comparisons of the two in which the model tended to underestimate costs by 7.3 percent. Using this model for future predictions yielded an O&S cost in FY2024 of \$9.5M per ship which was a four percent decrease from the FY2010 actual recorded cost of \$9.9M. This decrease was assumed to be driven by the low reporting of manning costs. If more reliable manning figures were used, the estimated costs would rise about \$1.5M.<sup>39</sup>

<sup>39</sup> Assuming an average annual salary of \$80K for each of the 19 crew members on board.

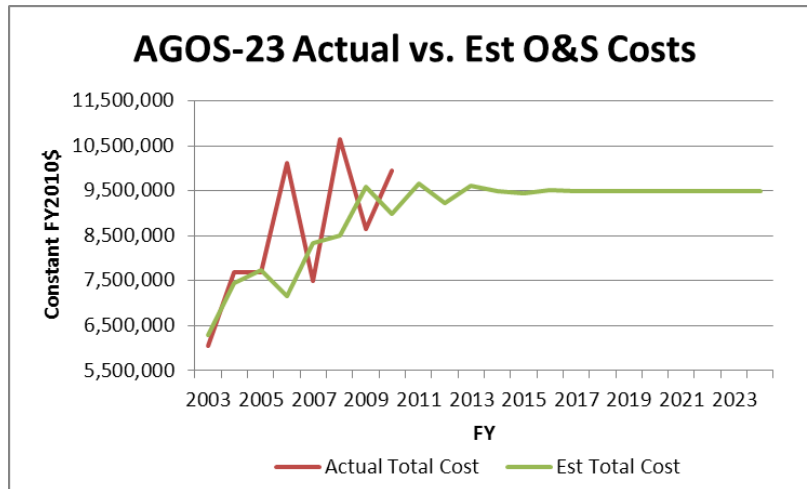


Figure 54. Testing and Projection of AGOS-23 Regression Model

FY	Actual Total Cost	Est Total Cost	Variance	Variance %
2003	6,052,143	6,298,910	246,767	4.1%
2004	7,676,781	7,448,016	-228,765	-3.0%
2005	7,694,310	7,741,096	46,786	0.6%
2006	10,112,442	7,162,674	-2,949,768	-29.2%
2007	7,498,142	8,346,488	848,346	11.3%
2008	10,645,428	8,517,089	-2,128,339	-20.0%
2009	8,645,424	9,581,395	935,971	10.8%
2010	9,949,765	8,993,570	-956,195	-9.6%
AVERAGE			-849,997	-7.3%

Table 25. AGOS-23 O&S Cost Variances

## 27. Salvage Ship (ARS-50)

Although within its 20s in regards to age, the cost data for the salvage ships depicted in Figure 55 were only attainable for the last five years. In addition, no successful regression was able to be calculated so a three-year moving average model was used in its place.

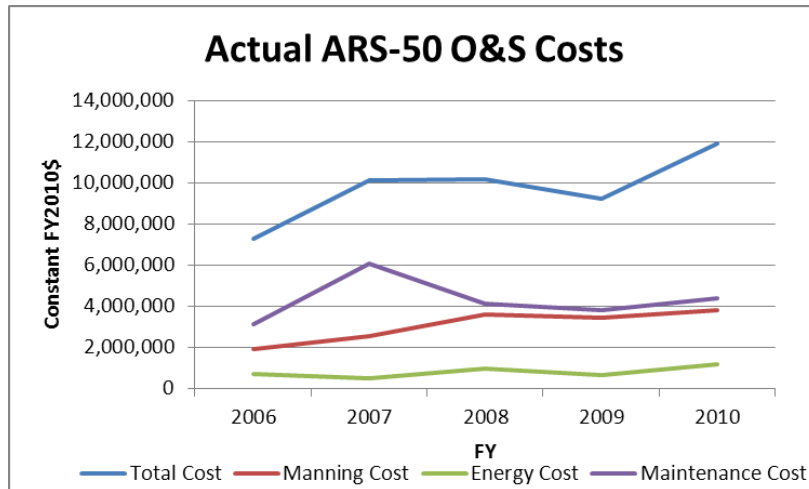


Figure 55. ARS-50 Costs by Top Three Cost Drivers

A comparison of the results of the averaging model with the actual O&S costs recorded over the last five years was completed and Figure 56 and table 26 show the comparison of the two. Using this model for future predictions yielded an O&S cost in FY2024 of \$10.8M per ship which was a nine percent decrease from the FY2010 actual recorded cost of \$11.9M. This decrease was assumed to be driven by the model in which few data years were available for trend analysis.

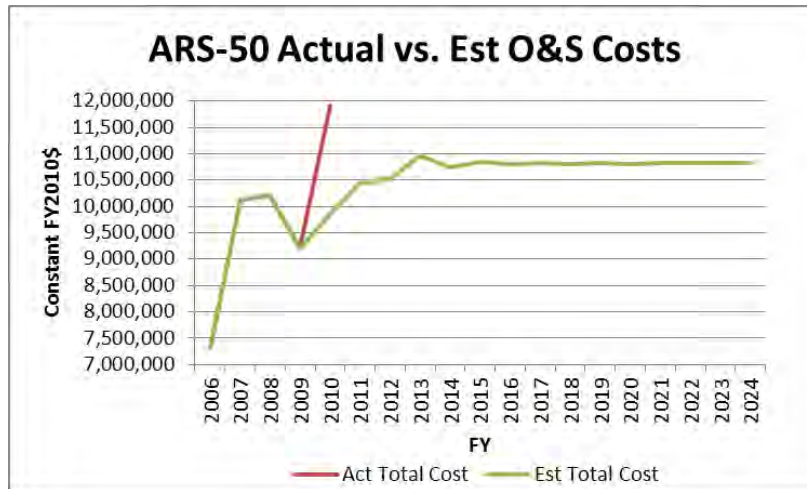


Figure 56. Testing and Projection of ARS-50 Model

FY	Actual Total Cost	Est Total Cost	Variance	Variance %
2006	7,311,035	7,311,035	0	0.0%
2007	10,115,660	10,115,660	0	0.0%
2008	10,205,889	10,205,889	0	0.0%
2009	9,222,023	9,210,861	-11,162	-0.1%
2010	11,904,678	9,847,857	-2,056,821	-17.3%
AVERAGE			-413,597	-3.5%

Table 26. ARS-50 O&S Cost Variances

## 28. Fleet Ocean Tug (ATF-166)

Across all three cost areas, the reduction in costs have driven the total O&S costs for the fleet ocean tugs downward in an almost linear fashion. Costs have steadily dropped from a recorded high in FY1996 of just over \$9M to as low as \$5M in FY2007, as seen in Figure 57.

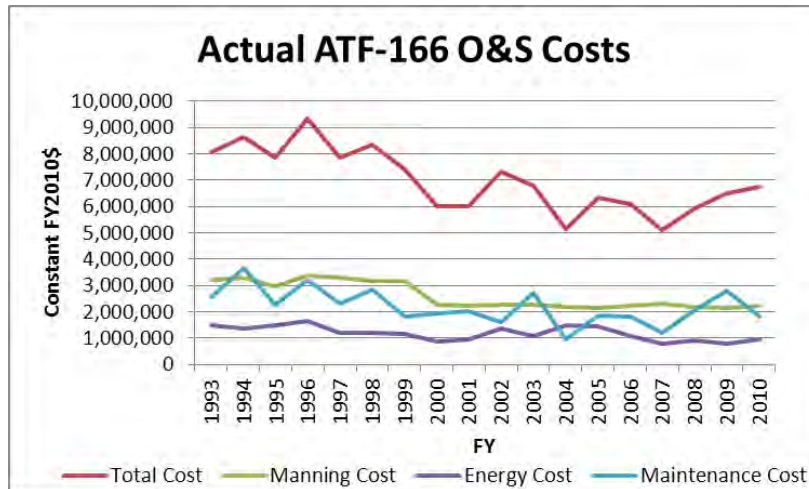


Figure 57. ATF-166 Costs by Top Three Cost Drivers

A comparison of the results of the averaging model with the actual O&S costs recorded over the last 18 years was completed and Figure 58 and Table 27 show the comparison of the two. Using this model for future predictions yielded an O&S cost in FY2024 of \$6.5M per ship which was a three percent decrease from the FY2010 actual recorded cost of \$6.7M. This decrease was assumed to be driven by the downward trending of all costs throughout the years.

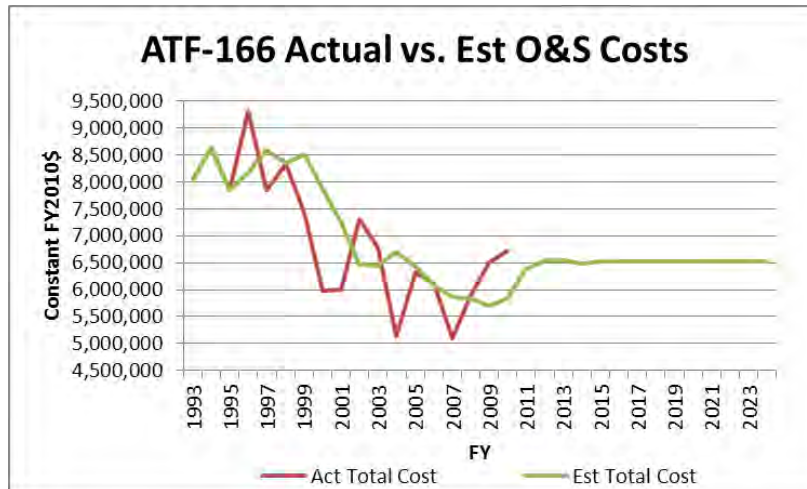


Figure 58. Testing and Projection of ATF-166 Model

FY	Actual Total Cost	Est Total Cost	Variance	Variance %
1993	8,051,700	8,051,700	0	0
1994	8,630,616	8,630,616	0	0
1995	7,843,674	7,843,674	0	0
1996	9,318,711	8,175,330	-1,143,381	-0.1226974
1997	7,855,636	8,597,667	742,031	0.0944584
1998	8,327,113	8,339,341	12,227	0.00146837
1999	7,418,904	8,500,487	1,081,583	0.14578739
2000	5,983,911	7,867,218	1,883,307	0.31472843
2001	6,005,605	7,243,310	1,237,705	0.20609156
2002	7,315,280	6,469,473	-845,806	-0.1156219
2003	6,790,700	6,434,932	-355,768	-0.0523905
2004	5,133,827	6,703,862	1,570,035	0.30582161
2005	6,327,351	6,413,269	85,918	0.01357887
2006	6,095,315	6,083,959	-11,356	-0.0018631
2007	5,107,410	5,852,164	744,754	0.14581829
2008	5,907,001	5,843,359	-63,642	-0.010774
2009	6,510,944	5,703,242	-807,702	-0.1240529
2010	6,730,167	5,841,785	-888,382	-0.132
AVERAGE			-205,266	-2.5%

Table 27. ATF-166 O&S Cost Variances

## 29. Mobile Landing Platform Ship (MLP-1)

As a future ship for the battle force, the MLP had no acquisition cost data detailing what the expected O&S costs would be. Three ships are scheduled to be produced and commissioned into the fleet before FY2024. The design of the mobile

landing platforms is expected to be based on the Alaska class oil tanker, which is a part of the VLCC (super tanker) category of crude oil ships.<sup>40</sup> According to Frontline Ltd, the biggest operator of VLCC's, it required \$32.9K a day or \$12M annually to simply break even when operating one its VLCC ships. Using this figure as an expert/analogous estimate for the new MLP's, the expected cost of each MLP-1 class ship in FY2024 was also \$12M.

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<sup>40</sup> VLCC = Very large crude carrier.

## V. DATA ANALYSIS – AFFORDABILITY

The bottom line up front is that the Navy cannot afford a 324 ship battle force in FY2024 without seriously altering the way it does business. The reasoning behind this conclusion is described in the subsequent sections of this chapter.

### A. FACTORS AFFECTING AFFORDABILITY

#### 1. Battle Force Cost Models

From the cost models produced in Chapter IV, the total O&S costs for the entire 324 ship battle force in FY2024 was estimated to be just under \$20B. As shown in Figure 59, this is a 17 percent increase from the FY2010 288 ship battle force costs of \$17B.<sup>41</sup> **Note: An increase from 288 to 324 ships is 12.5 percent in fleet size, whereas the cost for this increase is 17 percent.**

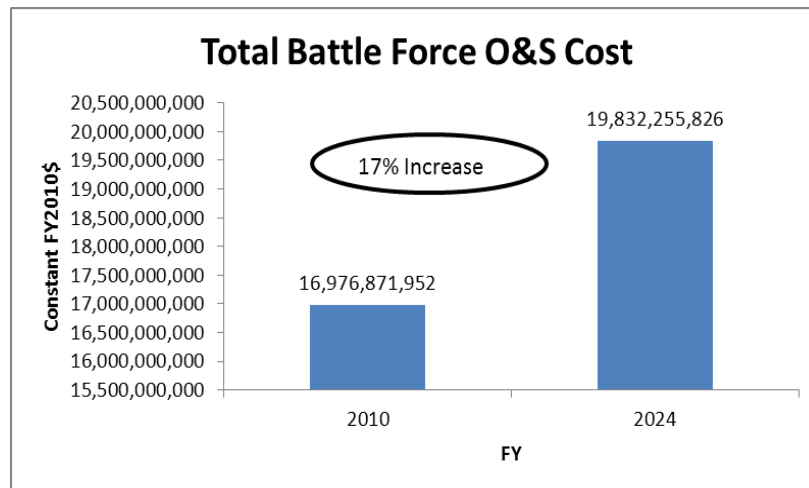


Figure 59. Total Battle Force O&S Costs

This \$3B FY2010 constant dollars growth to the battle force budget is believed to be an understatement of the true costs for three reasons. First, from the cost variance tables provided throughout Chapter IV, the cost models for 18 out of the 29 classes of ships resulted in the tendency to underestimate the costs of each ship within its particular

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<sup>41</sup> Numbers are rounded.

class. That is to say, 62 percent of the cost estimate models that were used tended to yield costs that were on average slightly lower than the true costs observed.<sup>42</sup> It is therefore believed that the \$20B cost estimate in FY2024 is most likely an underestimation as well. With that said, the scale of cost variances when viewed from an entire battle force cost viewpoint is a matter of tens of millions of dollars which can be assumed to be a moot point when viewing costs in the billions.

Second, the FY2024 cost estimate is believed to be an understatement due to the point listed under the assumptions section of Chapter III in which costs associated with embarked squadrons were not incorporated into the costs analysis for the various aircraft carrier and amphibious ships under review. Since an aircraft carrier's crew size for example, can essentially double while on deployments, manpower costs were understated in the O&S costs listed within the VAMOSC database and therefore in this thesis. This same logic can be applied for aircraft fuel and maintenance costs within these classes of ship. As a result, it was believed that true O&S costs were at least one to two billion dollars higher than estimated in this thesis. However, this factor was already taken into consideration and assumption noted when measuring the historical costs of the FY2010 battle force and creating the models and FY2010/FY2024 comparisons for all classes of ship.

Third, through yet another point listed under the assumptions section of Chapter III, manpower costs for submarines, Littoral Combat Ships (LCS) and Joint High Speed Vessels (JHSV) were all understated since they did not capture the other part of the crew in the Blue-Gold crew composition. For instance, with a reported onboard crew size of 42, a JHSV's manning costs were on average \$4M according to its SAR estimate. Since these ships used a Blue-Gold rotational crew, the true size of the JHSV crew should instead be 84 personnel, one team of 42 actually on board and one team ashore. With 21 JHSV's expected to be a part of the battle force in FY2024, \$84M of additional manning costs were neglected from the estimate for this class of ship alone. Add the same

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<sup>42</sup> This does not include the assumption that point estimates would mostly likely yield underestimates as well since their associated costs remained stagnant over time.

reasoning for the LCS and that would be another \$90M, equating to a total of \$174M in underestimation for these two class platforms to the overall battle force costs.

## **2. Battle Force Mix**

By far the largest component to determining affordability of the FY2024 battle force would be through the determination of the exact mix of ships in that force. As it stood during this analysis, the battle force mix illustrated earlier in Table 3 of Chapter IV shows the breakdown of the 324 ships expected by the Navy; the estimated costs of which was \$20B from the cost models. This mix of ships could be extremely volatile since delays in procurements or deliveries of one ship, extensions of others, or simply the rearrangement of classification of ships within the battle force can all greatly impact the cost structure involved. This therefore creates an opportunity for the future cost estimate made in this thesis and future estimates made by others to be very sensitive to change.

As mentioned previously, the increase in O&S costs from FY2010 to FY2024 is expected to be 17 percent. Simply adding one aircraft carrier to the 11 already in the fleet would add between \$392M–\$475M or three percent to the total cost growth, depending on the type of carrier and when it was added. In fact, despite force levels being less than 324 in earlier years such as in FY2022, there is the expectation of having 12 aircraft carriers in the fleet at that time potentially making the overall battle force more expensive. Making other subtle adjustments such as increasing the Guided Missile Cruisers by two and reducing the Joint High Speed Vessel by two would increase total costs in FY2024 by another one percent. The variations of ship mix are seemingly endless and therefore can alter a cost estimate dramatically. Refer to Table 5 in Chapter IV for the breakdown in annual ship costs to further illustrate the sensitivity that a particular battle force mix might have on O&S costs.

## **3. Navy O&S Budget**

Since Operating and Support costs were associated with both the Military Personnel and Operation and Maintenance Navy budget accounts, both the MPN and OMN budgets were reviewed. As depicted in Figure 60, 13 years of actual budget data

(FY1998–2010) were utilized to forecast what the future budgets would perhaps look like from FY2011–2024.

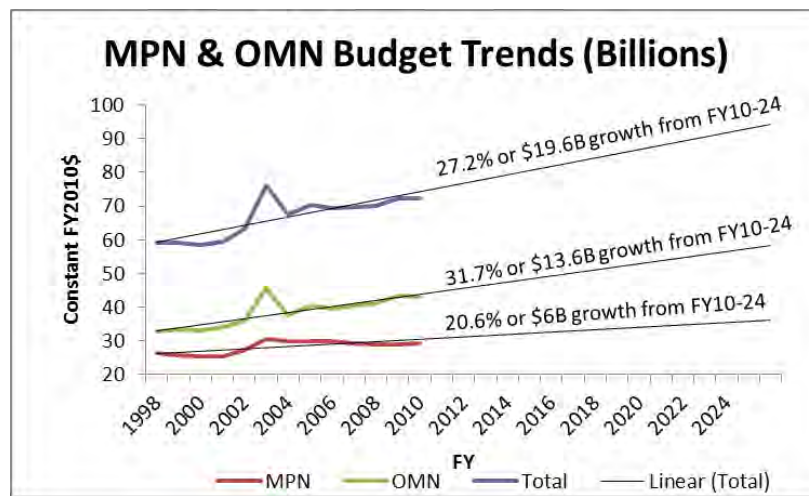


Figure 60. MPN and OMN Budget Growth Trends (From: <sup>43</sup>)

When reviewing the growth percentages from FY1998–2010, there was an actual growth of 31.2 percent within the OMN budget and a 22 percent growth in the total OMN/MPN combined total budget. Using linear trend line forecasting for the future, the OMN budget appeared to grow at 31.7 percent and the combined total budget by 27.2 percent leading into FY2024.<sup>44</sup> In another words, the OMN and combined MPN and OMN budgets had grown at fairly similar rates which is indicative of linear trend line forecasting.

This forecast was interesting because while the budgets grew at these rates from FY1998 to 2010, the size of the Navy's battle force had shrunk by 13.5 percent from 333 to 288 ships during this same time. See Figure 61. Yet, although the budgetary growth rates were expected to continue at similar rates into the future, the battle force size is no longer shrinking but instead now growing by 12.5 percent or 36 ships.

<sup>43</sup> Cost data from 1998–2010 are actual costs recorded in Military Personnel Navy and Operation and Maintenance Navy annual budget reports which were provided on Department of Navy Financial Manager and Comptroller website. <http://www.finance.hq.navy.mil/fmb/12pres/BOOKS.htm>

<sup>44</sup> Linear trend line forecasting is a tool available in Microsoft Excel 2010.

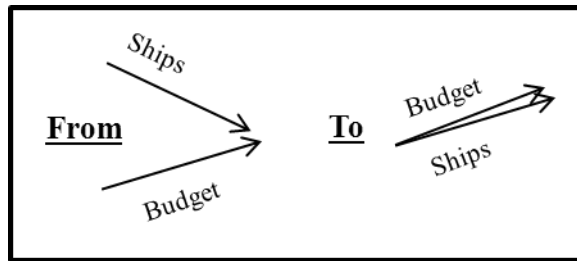


Figure 61. Ship Count vs. Budget Trend Relationship

This reversal in relationship between ship count and budget allocation from past to future causes a very obvious dilemma. The amount of money allocated specifically for each ship’s personnel, fuel and maintenance costs is subsequently forced to change as more ships are now added instead of being removed from the fleet. More funding will be required to be shifted away from other activities that may have grown expectant of those funds in order to meet the added operating and support costs of this larger fleet.

Since funding has already been extremely tight over the years resulting in difficulties in meeting operating and support costs, so much so that the Navy “remains dependent upon the receipt of OCO or similar supplemental appropriations to fund ship maintenance requirements,” adding more ships in the future while funding growth levels remain similar does not seem to pass the “logic test”.<sup>45</sup> This is of course assuming the very-likely defense budgetary cuts ranging in the hundreds of billions of dollars over the next ten years do not occur, which is certainly not a logical assumption to make.

Additionally, about 70 percent of the ships that are expected to be in service in FY2020 are made up of ships currently in commission.<sup>46</sup> This means that a majority of the ships that will make up the battle force in the early 2020s will be older ships, resulting in possibly higher maintenance costs incurred and therefore higher funding levels

<sup>45</sup> Quote extracted from statement provided to House Armed Service Readiness Committee on Navy Readiness given by Vice Admiral William Burke (Deputy Chief of Naval Operations Fleet Readiness & Logistics) and Vice Admiral Kevin McCoy (Commander, Naval Sea Systems Command) on 12July2011. OCO funds are additional funds requested by the military for Overseas Contingency Operations (OCO).which are separate from the funds requested in the President’s budget each year.

<sup>46</sup> Source: Statement provided to House Armed Service Readiness Committee on Navy Readiness given by Vice Admiral William Burke (Deputy Chief of Naval Operations Fleet Readiness & Logistics) and Vice Admiral Kevin McCoy (Commander, Naval Sea Systems Command) on 12July2011.

required. Ships such as the Command Ship (LCC) will have been extended past their original service life expectancies and others such as the Guided Missile Cruiser (CG) will have just began to reach their life expectancies. Since “we continue to see shortfalls throughout the fleet including...fewer spare parts available and more than \$815 million of unfunded maintenance requirements,” a combination of an aging and enlarged fleet, even for just a few years, can be problematic in terms of affordability.<sup>47</sup>

#### **4. Navy Cost Reduction Initiatives**

In terms of how the Navy plans to counter this affordability dilemma, scores of possible scenarios have been considered and most seem to center on the manning and fuel cost reduction initiatives. In fact, when asked during a visit to the Naval Postgraduate School, the Secretary of the Navy Ray Mabus responded with a strategy of using a series of cost reduction initiatives that addressed all three cost factors (manning, fuel and maintenance) reviewed in this thesis. The ones of interest which he alluded to were: 1) reduced manning on the new Ford Class aircraft carriers, Littoral Combat Ships, and Joint High Speed Vessels would all help lower the manning costs and address affordability issues while also “moving people from desk jobs to either the pier or on the ship...” to help aid in the process; and 2) energy initiatives such as the installation of Hybrid Electric Drives (HED) on all Guided Missile Destroyers that would help with fuel costs.<sup>48</sup>

##### ***a. Manning Initiatives***

In terms of all the data reviewed and produced from the VAMOSC database, SAR cost reports, and the FY2024 cost estimates calculated in this thesis, the reduced manning on all three of the ships mentioned above does almost nothing with regards to cost savings for the Navy. As mentioned in the Ford aircraft carrier section of Chapter IV, although it is true that reduced manning onboard the new Ford aircraft

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<sup>47</sup> Comment made by Virginia Congressional Representative Randy Forbes on 12 July 2011.

<sup>48</sup> Quote: SECNAV Mabus during Secretary of the Navy Guest Lecture (SGL) at the Naval Postgraduate School on 29 August 2011.

carriers are expected to be less than the current Nimitz class ships, other costs such as increased maintenance costs would ultimately cause O&S costs to be very similar to the older Nimitz class ships in the end.<sup>49</sup>

As far as the Littoral Combat Ship goes, it was intended to completely replace the Guided Missile Frigates by the end of FY2020; yet actual O&S costs recorded by the Navy in VAMOSOC have shown that the LCS has been more expensive so far than the FFG's. The O&S costs on a FFG in FY2010 were \$29.2M with an average over the last 20 years of \$27.8M, whereas the O&S costs for a LCS were 25 percent higher or \$36.4M; and this amount did not include the additional manning costs associated with the other part of the LCS' Blue-Gold crew mentioned earlier.

With regards to the Joint High Speed Vessel, this ship was not officially planned to replace any others in the Navy's current battle force structure. Even with a smaller crew size, the average O&S costs for just one ship were expected to be \$27.6M which is actually more than a FFG when including the additional \$4M for the rest of the Blue-Gold crew that is associated with the ship. With about 21 of these ships expected in FY2024, that's an added \$660M to the Navy's budget for a new class of ship that is replacing no others.

Finally, in addressing the idea of shifting personnel from shore commands to either the pier or to the new ships in order to offset the need to recruit more personnel, the effect is minimal. Again, the cost difference from a 288 ship to a 324 ship battle force Navy is at a minimum \$3B according to this thesis' estimates. Assuming that, on average, a sailor cost \$80K each, then approximately 37.5K personnel would be required to shift from shore to sea to make up for that \$3B difference—a very unlikely, if not impossible, feat.

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<sup>49</sup> This is again only when compared in FY2010. Since a point estimate was used for CVN-78, no price growth was included and therefore became increasingly different than that of CVN-68 leading into FY2024 since CVN-68 did have a price growth.

***b. Hybrid Electric Drive (HED) Initiative***

Before reviewing the potential cost savings and effects on affordability that the Hybrid Electric Drives (HED) would provide the Navy, it is worth looking at the fuel costs (prior-to-HED-technology) that were incurred over the last 20 years by the major combatant ships that comprise the current FY2010 battle force. Referring to Figure 62, fuel cost data derived from VAMOSC were broken down to their simplest form, cost per gallon of fuel. Focusing on the darker line labeled “Average,” it is safe to say that costs per gallon for the major combatant ships in the battle force remained rather steady, costing an average of \$2.2–\$2.7 per gallon over the last two decades for the nine ships reviewed here. This is extremely interesting since the whole push for HED was due to concerns over rising fuel prices over the years. The data here simply do not support that concern.<sup>50</sup>

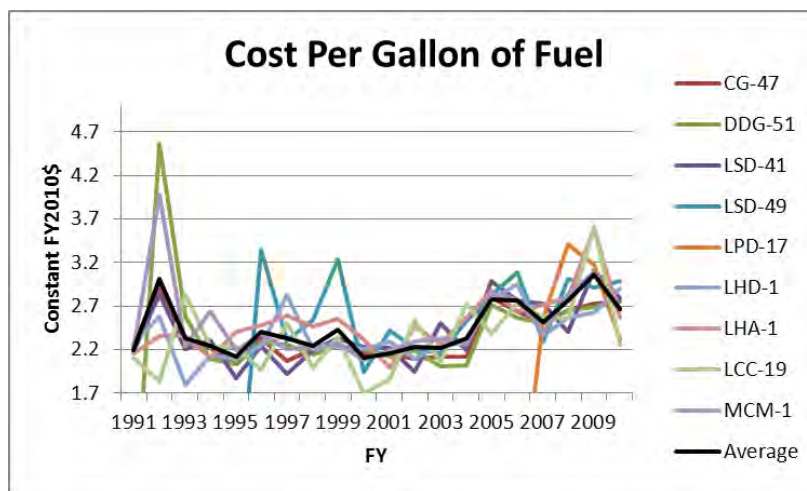


Figure 62. Cost Per Gallon of Fuel for Combatant Ships

With regards to the potential cost savings to the total battle force for the inclusion of a Hybrid Electric Drive on Guided Missile Destroyers, the savings is minimal when compared to the \$3B increase in total costs in FY2024 for the 36 added

<sup>50</sup> Although there is a fairly obvious upward trend in price per gallon from \$2.2 to \$2.7, this 22.7 percent price growth was over a 20 year span. Assuming the same growth rate in the next 20 years, the added fuel costs during this time would be about \$3.31 in FY2030 which is only a three cents increase per year.

ships expected. According to a DRS Technologies technical report, “assuming a 12-knot system and the operating profile used in this study, fuel savings are estimated at 4800 barrels per ship per year for the motoring-only case and 8900 barrels per ship per year for the motoring-generating case.”<sup>51</sup> This equates to approximately 373.8K gallons of fuel per ship or 29.9M gallons for all 80 DDG’s in FY2024, assuming all 80 ships have the technology at that time. Further assuming a cost per fuel gallon of \$3 which is higher than the historical 20 year average to date, the savings to the fleet would be on the high end of \$90M in FY2024. With total O&S costs for that year expected to be at least \$20B, this is less than half of one percent savings, although a large number by itself, would not be large enough to make any difference in the larger scheme of O&S costs.

## **B. AFFORDABILITY CONCLUSION**

“During inspections in the last two years, more than 1 in 5 Navy vessels were deemed less than satisfactory or unfit for combat.”<sup>52</sup> If the Navy is already struggling to meet funding requirements to properly man, fuel and maintain a fleet of 288 ships in FY2010, the prospect of somehow reversing that trend for an even larger fleet of 324 ships in FY2024 when budgets are more likely to be greatly cut, does not seem to hold much merit. Even with the cost reduction initiatives in the works and more on the way within the lifelines of the Navy, they are simply not enough to counter the added costs that the additional 36 ships in the battle force will create.

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<sup>51</sup> Source: Economic Benefits of Hybrid Drive Propulsion for Naval Ships.  
<http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=04906560>

<sup>52</sup> Virginia Representative Randy Forbes in statement made in The Washington Times on 13July2011.

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## VI. CONCLUSION

### A. SUMMARY OF FINDINGS

- Referring back to Table 4, the following cost estimation models were derived through analysis of the three largest cost areas (manning, fuel and maintenance) for each class of ship:<sup>53</sup>
  - Estimation models used for **total O&S costs** within a class of ship:
    - 17 regression estimation models
    - Five point estimation models
    - Five 3-year moving average estimation models
    - Two export or analogous estimation models
  - Estimation models used for **total manning costs** within a class of ship:
    - 10 regression estimation models
    - Six 3-year moving average estimation models
  - Estimation models used for **total fuel costs** within a class of ship:
    - Four regression estimation models
    - Six 3-year moving average estimation models
  - Estimation models used for **total maintenance costs** within a class of ship:
    - 15 3-year moving average cost estimation models
- No regression models were attainable in measuring maintenance costs for any of the classes of ships reviewed.
- 18 out of the 29 “total O&S cost” estimation models tended on average to yield lower cost estimations when compared to actual costs recorded in VAMOSC.
- In terms of cost volatility, more often than not, fuel costs were the most stable followed by manning costs and then maintenance costs. By far, maintenance costs were the most volatile cost factor in O&S costs on average.

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<sup>53</sup> Although there were 29 cost estimation models, not all of them utilized manpower, fuel or maintenance as a variable within their regression equations. In other cases, 3-year moving averages or point estimates were used in place of regression models altogether.

- O&S costs were quite sensitive to the particular mix of ships within the battle force during any given year. A higher number of ships in the battle force in a later year did not necessarily indicate higher expected O&S costs. Instead, it depended on the particular mix of ships within that battle force.
- A 324 ship Navy was estimated to raise O&S costs by a minimum of 17 percent in FY2024 (constant FY2010 dollars) from the costs recorded for a 288 ship battle force in FY2010.
- Reduced manning as a cost reduction initiative for the new Ford class aircraft carrier (CVN-78) and Littoral Combat Ship (LCS) provide almost negligible savings to the Navy since higher maintenance and other costs make up for the difference. In fact, the new CVN-78 aircraft carriers are expected to have similar O&S costs to the older CVN-68 class aircraft carriers. The LCS and Joint High Speed Vessels have already proven to cost more than the Guided Missile Frigate of which the LCS was designed to replace.
- Hybrid Electric Drives (HED) as a cost reduction initiative is expected to provide less than one percent in overall O&S cost savings which is negligible when increased O&S costs from the additional 36 ships added to the fleet are incurred.

## **B. CONCLUSION**

Assuming the Navy OMN and MPN budgets continue their historical growth trends into FY2024, essentially escaping any budgetary reductions until then, the Navy will still not be able to afford to properly operate and maintain a battle force fleet of 324 ships. As Congressman Forbes has publicly stated, “our Navy already has insufficient resources to preserve its current fleet...”<sup>54</sup> With a minimum O&S cost growth of 17 percent by adding these 36 extra ships to the battle force, the Navy would be forced to provide more funding despite less funding available which would amplify the already existent problem of underfunding and scarcity within the fleet as it is.

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<sup>54</sup> Representative Randy Forbes; a Virginia Congressman and chairman of the House Armed Services Readiness Committee.

### **C. RECOMMENDATIONS**

Rather than “kicking the can down the road” with regards to determining how to possibly afford a 12.5 percent growth to the Navy’s battle force sometime in the future, probably when it is too late, the Navy should realistically plan for it now. The framework for including O&S costs and affordability is already in place since feasibility and affordability analysis for both R&D and procurement are currently completed in these annual shipbuilding plans. Use of cost estimation models such as the ones in this thesis would allow for simple inclusion of O&S cost analysis in these reports as well. Therefore, it is recommended that the Navy include within its shipbuilding plan to congress the expected O&S costs and affordability analysis of the future battle force each year in order to fully understand the magnitude and feasibility of what is being proposed.

### **D. AREAS FOR FUTURE STUDY**

- Capture the full O&S costs associated with embarked squadrons aboard certain classes of ships such as aircraft carriers and amphibious ships.
- Capture full manpower costs (Blue-Gold teams) for submarines, Littoral Combat Ships (LCS) and Joint High Speed Vessels (JHSV) since they were not fully recorded in the cost data reviewed.
- Analyze the affordability aspect of an enlarged future battle force after the Navy begins facing the large budgetary cuts that are currently being proposed and introduced to the Defense Department.
- Attempt to successfully derive regression models for maintenance costs associated with each ship class instead of having to resort to 3-year moving average models.
- Update the cost estimation models, especially where point estimates or 3-year moving averages were used because of little or no actual historical cost data available at the time.

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## APPENDIX A

<b><u>Operating and Support Cost Categories</u></b>
Unit-Level Manpower
Operations Manpower
Unit-Level Maintenance Manpower
Other Unit-Level Manpower
Unit Operations
Operating Materiel
Energy (Fuel, Electricity, etc.)
Training Munitions and Expendable Stores Other Operational Materiel
Support Services
Temporary Duty
Maintenance
Organizational Maintenance and Support Intermediate Maintenance
Depot Maintenance
Sustaining Support
System Specific Training
Support Equipment Replacement
Operating Equipment Replacement
Sustaining Engineering and Program Management
Other Sustaining Support
Continuing System Improvements
Hardware Modifications or Modernization Software Maintenance and Modifications Indirect Support
Installation Support
Personnel Support
General Training and Education

Table 28. O&S Categories according to the 2011 Defense Acquisition Guidebook

From MSC Universe

Fiscal Year	Element1	Element1 Desc	Constant FY10 Dollars	Count
2010	1.0	Unit-Level Manpower	24,115,151	
2010	2.0	Unit Operations	10,062,765	
2010	3.0	Maintenance	43,893,554	
2010	4.0	Sustaining Support	41,145,719	
2010	5.0	Boating System Improvements	6,542,536	
2010	6.0	Indirect Support	1,288	
2010	A.0	Number of Ships		2
2010	B.0	Total Personnel		155
2010	C.0	Total Hours		13,824
2010	D.0	Total BBLs Fuel		40,877
Sum:			125,861,011	

From SHIPS Universe

Fiscal Year	Ship Class	Element1	Element1 Desc	Constant FY10 Dollars	Count
2010	AS-39CL	1.0	Direct Unit Cost	93,222,301	
2010	AS-39CL	2.0	Maintenance - Inter	2,092,433	
2010	AS-39CL	3.0	Maintenance & Moc	19,058,268	
2010	AS-39CL	4.0	Other Operating & S	2,866,989	
2010	AS-39CL	A.0	Number of Ships or		1
2010	AS-39CL	B.0	Percent FY		100
2010	AS-39CL	C.0	Number of Personr		1,115
2010	AS-39CL	E.0	Hours - Steaming T		2,952
2010	AS-39CL	F.0	Barrels of Fuel Con		3,245
2010	AS-39CL	G.0	Manhours - Org Co		32,720
2010	AS-39CL	H.0	Manhours - Interme		42,339
2010	AS-39CL	K.0	Mandays Total		25,214
2010	AS-39CL	L.0	Days - Steaming U		6
2010	AS-39CL	M.0	Ship Age		31
Sum:				117,239,991	

Figure 63. Difference in Cost Data Reports of AS-39

## APPENDIX B –CORRELATION TESTS OF VARIABLES

<b>CVN-68 Correlation Matrix</b>				
	<i>Manning Cost</i>	<i>Total Maintenance</i>	<i>FY</i>	<i>Manning #</i>
Manning Cost	1			
Total Maintenance	0.661377933	1		
FY	0.935356813	0.572700212	1	
Manning #	0.418674603	0.552946202	0.17471	1

Table 29. CVN-68 Correlation Matrix of Regression Variables

<b>CG-47 Correlation Matrix</b>							
	<i>Manning Cost</i>	<i>Fuel Cost</i>	<i>Total Maintenance</i>	<i>Manning #</i>	<i>FY</i>	<i>\$/Gal</i>	<i>u/w hrs</i>
Manning Cost	1						
Fuel Cost	0.073463651	1					
Total Maintenance	0.644024754	0.1010858	1				
Manning #	-0.212772869	0.1542635	-0.589681995	1			
FY	0.9079342	-0.0687042	0.798601846	-0.51437	1		
\$/Gal	0.285626857	0.6461404	0.409799031	-0.4231297	0.4028245	1	
u/w hrs	-0.082486012	0.6613325	-0.039035827	0.4588999	-0.311235	-0.03658	1

Table 30. CG-47 Correlation Matrix of Regression Variables

<b>DDG-51 Correlation Matrix</b>							
	<i>Manning Cost</i>	<i>Fuel Cost</i>	<i>Total Maintenance</i>	<i>Manning #</i>	<i>FY</i>	<i>\$/Gal</i>	<i>U/W hrs</i>
Manning Cost	1						
Fuel Cost	-0.070143851	1					
Total Maintenance	0.714816273	-0.338836	1				
Manning #	-0.10503778	-0.073849	-0.235126011	1			
FY	0.887385999	-0.017565	0.767022857	-0.4770975	1		
\$/Gal	-0.090999848	0.7322693	-0.265602904	-0.0634353	-0.10794	1	
U/W hrs	0.127347912	0.3218652	0.016021453	-0.0954313	0.277821	-0.366466	1

Table 31. DDG-51 Correlation Matrix of Regression Variables

<b>SSN-21 Correlation Matrix</b>				
	<i>Manning Cost</i>	<i>Total Maintenance</i>	<i>FY</i>	<i>Manning #</i>
Manning Cost	1			
Total Maintenance	0.722478239	1		
FY	0.784594604	0.907401277	1	
Manning #	0.857270857	0.634643689	0.590365289	1

Table 32. SSN-21 Correlation Matrix of Regression Variables

<b>SSN-688 Correlation Matrix</b>				
	<i>Manning Cost</i>	<i>Total Maintenance</i>	<i>FY</i>	<i>Manning #</i>
Manning Cost	1			
Total Maintenance	0.425316672	1		
FY	0.918218189	0.139568378	1	
Manning #	0.673173718	0.880712218	0.408933	1

Table 33. SSN-688 Correlation Matrix of Regression Variables

<b>SSN-774 Correlation Matrix</b>				
	<i>Manning Cost</i>	<i>Total Maintenance</i>	<i>FY</i>	<i>Manning #</i>
Manning Cost	1			
Total Maintenance	0.299698417	1		
FY	-0.254843392	0.812559251	1	
Manning #	0.596800688	-0.339173128	-0.81009	1

Table 34. SSN-774 Correlation Matrix of Regression Variables

<b>SSGN-726 Correlation Matrix</b>				
	<i>Manning Cost</i>	<i>Total Maintenance</i>	<i>FY</i>	<i>Manning #</i>
Manning Cost	1			
Total Maintenance	-0.528561575	1		
FY	0.913152424	-0.156457646	1	
Manning #	0.99352149	-0.587340609	0.878748	1

Table 35. SSGN-726 Correlation matrix of Regression Variables

<b>LHD-1 Correlation Matrix</b>							
	<i>Manning Cost</i>	<i>Fuel Cost</i>	<i>Total Maintenance</i>	<i>FY</i>	<i>Manning #</i>	<i>\$/Gal</i>	<i>U/W Hrs</i>
Manning Cost	1						
Fuel Cost	0.673569143	1					
Total Maintenance	0.308327136	0.2160222	1				
FY	0.930997805	0.578608	0.405884815	1			
Manning #	0.278135078	0.3670073	0.134798387	0.268328	1		
\$/Gal	0.552114651	0.6230138	0.2776918	0.541452	-0.007041	1	
U/W Hrs	0.426496777	0.6263697	0.097243777	0.379101	0.3601561	-0.09974	1

Table 36. LHD-1 Correlation Matrix of Regression Variables

<b>LSD-41 Correlation Matrix</b>							
	<i>Manning Cost</i>	<i>Total Maintenance</i>	<i>Fuel Cost</i>	<i>FY</i>	<i>Manning #</i>	<i>\$/Gal</i>	<i>U/W Hrs</i>
Manning Cost	1						
Total Maintenance	0.540199776	1					
Fuel Cost	0.398276809	0.108031059	1				
FY	0.914665575	0.756072394	0.2120861	1			
Manning #	0.529616161	-0.071726362	0.5264097	0.241222	1		
\$/Gal	0.50883357	0.559494243	0.5983068	0.540233	0.251987345	1	
U/W Hrs	0.269872062	-0.073555766	0.7631417	0.065538	0.514308662	0.069421	1

Table 37. LSD-41 Correlation Matrix of Regression Variables

<b>LSD-49 Correlation Matrix</b>							
	<i>Manning Cost</i>	<i>Fuel Cost</i>	<i>Total Maintenance</i>	<i>FY</i>	<i>Manning #</i>	<i>\$/Gal</i>	<i>U/W Hrs</i>
Manning Cost	1						
Fuel Cost	0.803916967	1					
Total Maintenance	0.497757091	0.491098	1				
FY	0.749361588	0.744357	0.7423435	1			
Manning #	0.294626049	0.002694	-0.102746657	-0.1082	1		
\$/Gal	0.039630737	0.26768	0.072340078	0.161824	-0.1687675	1	
U/W Hrs	0.689442494	0.814619	0.543032775	0.704166	0.09461439	-0.258327	1

Table 38. LSD-49 Correlation Matrix of Regression Variables

<b>MCM-1 Correlation Matrix</b>							
	<i>Manning Cost</i>	<i>Fuel Cost</i>	<i>Total Maintenance</i>	<i>FY</i>	<i>Manning #</i>	<i>\$/Gal</i>	<i>U/W Hrs</i>
Manning Cost	1						
Fuel Cost	-0.328959528	1					
Total Maintenance	0.164993474	-0.309716	1				
FY	0.928664888	-0.398555	0.175187313	1			
Manning #	0.176091749	0.002029	-0.112514863	-0.05055	1		
\$/Gal	0.00615627	0.003894	-0.263396741	0.107627	-0.2433948	1	
U/W Hrs	0.053952559	0.75916	-0.10094955	-0.03927	0.12853285	-0.49383	1

Table 39. MCM-1 Correlation Matrix of Regression Variables

<b>AO-187 Correlation Matrix</b>			
	<i>Manning Cost</i>	<i>Energy Cost</i>	<i>Maintenance Cost</i>
Manning Cost	1		
Energy Cost	-0.392687912	1	
Maintenance Cost	-0.339523662	0.83598638	1

Table 40. AO-187 Correlation Matrix of Regression Variables

<b><u>AOE-6 Correlation Matrix</u></b>						
	<i>Manpower Cost</i>	<i>Energy Cost</i>	<i>Maintenance Cost</i>	<i>FY</i>	<i>S/Gal</i>	<i>Hrs U/W</i>
Manpower Cost	1					
Energy Cost	0.958188679	1				
Maintenance Cost	-0.09077045	0.026167841	1			
FY	0.827401477	0.70568527	-0.397719017	1		
S/Gal	0.528032912	0.579793822	-0.135336486	0.555154	1	
Hrs U/W	0.97942815	0.94295564	-0.068784285	0.817797	0.414636	1

Table 41. AOE-6 Correlation Matrix of Regression Variables

<b><u>LCC-19 Correlation Matrix</u></b>							
	<i>Manning Cost</i>	<i>Fuel Cost</i>	<i>Total Maintenance</i>	<i>FY</i>	<i>Manning #</i>	<i>\$/Gal</i>	<i>U/W Hrs</i>
Manning Cost	1						
Fuel Cost	0.542925684	1					
Total Maintenance	0.282057292	-0.14182875	1				
FY	0.908681782	0.420526049	0.365782776	1			
Manning #	-0.371718311	-0.08610987	-0.441255433	-0.68561	1		
\$/Gal	0.510501792	0.539612385	0.395533507	0.455662	-0.11559353	1	
U/W Hrs	0.137803618	0.585291968	-0.293539555	0.01429	0.088210782	-0.23872	1

Table 42. LCC-19 Correlation Matrix of Regression Variables

<b><u>AS-39 Correlation Matrix</u></b>			
	<i>Manning Cost</i>	<i>Fuel Cost</i>	<i>Total Maintenance</i>
Manning Cost	1		
Fuel Cost	0.389640437	1	
Total Maintenance	0.119236677	-0.0326936	1

Table 43. AS-39 Correlation Matrix of Regression Variables

<b><u>AGOS-19 Correlation Matrix</u></b>			
	<i>Manning Cost</i>	<i>Energy Cost</i>	<i>Maintenance Cost</i>
Manning Cost	1		
Energy Cost	-0.123420505	1	
Maintenance Cost	-0.207195964	0.174696796	1

Table 44. AGOS-19 Correlation Matrix of Regression Variables

<b><u>AGOS-23 Correlation Matrix</u></b>			
	<i>Manning Cost</i>	<i>Energy Cost</i>	<i>Maintenance Cost</i>
Manning Cost	1		
Energy Cost	-0.595708545	1	
Maintenance Cost	-0.272082573	0.142804794	1

Table 45. AGOS-23 Correlation Matrix of Regression Variables

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## APPENDIX C – REGRESSION RESULTS

	F-significance	Adjusted R <sup>2</sup>	b0	b1	b2	b3	b4	b5
CVN-68	9.39277E-27	0.999031097	18841399.38	0.9997	1.01			
Man Pwr	3.03901E-11	0.935288857				-10,572,406,323.83	5293066.75	52603.22
Fuel	-	-						
Maintenance	-	-						

Table 46. CVN-68 Compiled Regression Results

	F-significance	Adjusted R <sup>2</sup>	b0	b1	b2	b3	b4	b5	b6	b7	b8	b9
CG-47	1.18014E-12	0.966973585	5813525.06	0.779815418	1.44	0.98						
Man Pwr	4.90981E-10	0.910229053					-1422266307	709175.68	71664.18			
Fuel	8.73085E-09	0.874051294								-8613812.73	3475709.52	3401.53
Maintenance	5.24254E-05	0.649473059										

Table 47. CG-47 Compiled Regression Results

	F-significance	Adjusted R <sup>2</sup>	b0	b1	b2	b3	b4	b5	b6	b7	b8	b9
DDG-51	1.14088E-13	0.980689666	9203461.42	0.858886666	0.69	0.95						
Man Pwr	1.91752E-09	0.908484419					-1331484798	664919.07	65851.15			
Fuel	2.01601E-10	0.930941969								-5447759.13	2718757.64	2463.54
Maintenance	0.000348141	0.584211993										

Table 48. DDG-51 Compiled Regression Results

	F-significance	Adjusted R <sup>2</sup>	b0	b1	b2	b3	b4	b5	b6
SSN-21	9.21491E-13	0.995300199	-4621230.48	1.571061889	0.98				
Man Pwr	2.75404E-07	0.962281385				-137057611.2	454775.58	32018.19	68305.61
Fuel	-	-							
Maintenance	-	-							

Table 49. SSN-21 Compiled Regression Results

	F-significance	Adjusted R <sup>2</sup>	b0	b1	b2	b3	b4	b5
SSN-688	1.16712E-09	0.900602094	-2206322.74	1.18	1.06			
Man Pwr	9.45008E-12	0.943597664				-603430066	299967.58	96349.71
Fuel	-	-						
Maintenance	-	-						

Table 50. SSN-688 Compiled Regression Results

	F-significance	Adjusted R <sup>2</sup>	b0	b1
SSN-774	0.002858715	0.952785566	13916711.61	0.96
Man Pwr	-	-		
Fuel	-	-		
Maintenance	-	-		

Table 51. SSN-774 Compiled Regression Results

	F-significance	Adjusted R <sup>2</sup>	b0	b1	b2	b3	b4	b5
SSGN-726	6.50237E-09	0.99925637	12565226.19	0.63	0.96			
Man Pwr	2.62558E-06	0.991799921				-540928170.8	270820.41	74896.64
Fuel	-	-						
Maintenance	-	-						

Table 52. SSGN-726 Compiled Regression Results

	F-significance	Adjusted R <sup>2</sup>	b0	b1	b2	b3	b4	b5	b6	b7	b8	b9
LHD-1	4.65257E-23	0.998349234	7359172.09	0.98	1.07	1.02						
Man Pwr	2.37596E-11	0.937135796					-4863077561	2426535.12	73085.94			
Fuel	3.58073E-08	0.851303305								-12190999.05	6719209.74	4053.76
Maintenance	-	-										

Table 53. LHD-1 Compiled Regression Results

	F-significance	Adjusted R <sup>2</sup>	b0	b1	b2	b3	b4	b5
LSD-41	3.05767E-14	0.971269012	2298033.5		1.323994249	0.95		
Man Pwr	5.45196E-11	0.93068292					-1049804083	525555.94
Fuel	N/A	N/A						
Maintenance	N/A	N/A						

Table 54. LSD-41 Compiled Regression Results.

	F-significance	Adjusted R <sup>2</sup>	b0	b1	b2	b3	b4	b5	b6
LSD-49	3.54731E-09	0.969292365	8090823.15	0.68	0.8	1.15			
Man Pwr	0.000667583	0.655096416							
Fuel	5.85078E-07	0.893303768					-4322509.23	1617496.26	1676.41
Maintenance	0.008096561	0.477206452							

Table 55. LSD-49 Compiled Regression Results

	F-significance	Adjusted R^2	b0	b1	b2	b3	b4	b5
MCM-1	3.22143E-12	0.950305265	414002.04	1.14	0.95			
Man Pwr	1.03734E-09	0.901971039				-434391391.5	218602.33	32673.23
Fuel	-	-						
Maintenance	-	-						

Table 56. MCM-1 Compiled Regression Results

	F-significance	Adjusted R^2	b0	b1	b2	b3
AO-187	4.48986E-08	0.963783074	-58723.93	1.08	1.07	1.24
Man Pwr	-	-				
Energy	-	-				
Maintenance	-	-				

Table 57. AO-187 Compiled Regression Results

	F-significance	Adjusted R^2	b0	b1	b2	b3	b4	b5	b6
AOE-6	1.72236E-08	0.997015133	4521491.55	1.05	0.64	1.14			
Man Pwr	0.006665132	0.692832297							
Energy	8.10857E-05	0.912849195					-9349462.52	3473551.81	4340.91
Maintenance	-	-							

Table 58. AOE-6 Compiled Regression Results

	F-significance	Adjusted R^2	b0	b1	b2	b3	b4	b5	b6
LCC-19	7.46559E-23	0.998248707	8301876.2	0.92	1.15	0.98			
Man Pwr	2.00874E-11	0.938365341					-2779652265	1395024.66	44651.23
Fuel	2.60724E-07	0.812181755							
Maintenance	-	-							

Table 59. LCC-19 Compiled Regression Results

	F-significance	Adjusted R^2	b0	b1	b2	b3
AS-39	6.62141E-11	0.945305486	17571905.32	0.93	1.31	0.82
Man Pwr	-	-				
Energy	-	-				
Maintenance	-	-				

Table 60. AS-39 Compiled Regression Results

	F-significance	Adjusted R^2	b0	b1	b2
AGOS-19	2.14149E-05	0.914966694	-1230125	2.64	1.15
Man Pwr	-	-			
Energy	-	-			
Maintenance	-	-			

Table 61. AGOS-19 Compiled Regression Results

	F-significance	Adjusted R^2	b0	b1	b2
AGOS-23	0.00042793	0.937096188	387549.87	1.44	1.06
Man Pwr	-	-			
Energy	-	-			
Maintenance	-	-			

Table 62. AGOS-23 Compiled Regression Results

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